STRUCTURAL PERFORMANCE OF EARTH BLOCKS STABILIZED WITH RICE HUSK ASH AND CEMENT

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(Construction Engineering and Management Option)

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Declaration

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

Signature .... Date ....

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This thesis research has been submitted for examination with our approval as the University Supervisors.

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Dedication

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Abstract

The conventional techniques of soil stabilization are becoming expensive day by day due to the rising cost of the stabilizing agents like, cement, lime, etc. The cost of stabilization and environmental hazards may be minimized by replacing a good proportion of stabilizing agent using the supplementary cementitious materials. Rice husks are among the waste material that must be managed in rice production areas.

This study investigated the structural performance of Rice Husk Ash (RHA) as partial replacement of cement to stabilize clay for the production of compressed earth blocks. Black cotton soil collected from a construction site was used in this study. Particle size distribution of the soil together with its Atterberg limits as well as its compaction characteristics were established according to British standard procedures (BS 1377-1990: Part 2 & 4). Stabilized soil specimens were prepared and tested for unconfined compressive strength, in accordance with BS 1924-2: 1990 Section 4.

The soil sample used was classified as A-7-5 in the AASHTO classification system. While increasing cement content resulted in decreased liquid limit, plasticity index and linear shrinkage; the same resulted in increased plastic limit, maximum dry density (MDD), and optimum moisture content (OMC). The cement stabilized clay blocks had an average compressive strength ranging from 0.3 MPa for 0% cement to 1.1 MPa for 12% cement at 7 days of curing; and 0.8 for 0% cement to 3.1MPa for 12% cement after 28 days of curing. This study established that to achieve a minimum strength of 2.5 MPa for soil blocks the soil should be stabilized with at least 8% cement. Replacement of cement with RHA led to a decrease in MDD, an increase

in OMC and a decrease in mean compressive strength of the blocks. The 28 day compressive strength for blocks stabilized with 5% cement and 7.5% RHA was 2.6MPa which was higher than the Kenyan Bureau of Standards requirements (2.5 MPa). It was not possible to measure water absorption of soil blocks after soaking for 24 hours. This is because blocks stabilized with 8% cement alone crumbled after 12 hours while the blocks stabilized with 5% cement and 7.5% RHA crumbled six hours after being immersed in water. These results suggest that stabilized earth blocks should only be used in an environment which is not exposed to water.

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CHAPTER ONE: INTRODUCTION

1.1 Background

The Kenyan population is experiencing a steady growth rate as shown by population census undertaken in 2009. Unfortunately, this growth is not commensurate with the growth in the housing sector. Statistics has it that Kenya has not been able to meet the ever rising housing demand with a short fall currently standing at over 150,000 units annually (KNBS, 2009). One key reason for housing inadequacy is the increase in population and the relatively high cost of permanent building materials (K'Akumu, 2004). Many people still languish in poverty without appropriate shelter which has led to the growing need for housing affecting all major towns in Kenya. This has been evidenced by the growing slums in the urban areas. In addition, the rural population is slowly facing housing problems and the country is in need of sustainable housing to cater for the constitutional right of every citizen.

Various factors have contributed to the inability to realize this objective of provision of decent and sustainable housing (K'Akumu, 2004). Firstly, the resources used for construction of housing in Kenya are becoming scarce by the day and the construction of new buildings consume huge quantities of materials, such as paving block, bricks, tiles, cement, aggregates. Most construction work still utilizes stones from quarries that have become more expensive due to the high demand. Over exploitation of the quarries has also raised environmental concerns leading to the closure and regulation of this mining activity.

1.2 Lowering cost of construction

The cost of construction materials such as cement, steel and timber has increased significantly (Uche and Ahmed, 2013). The use of earth and by-products from manufacturing processes presents a better option in lowering the cost of construction (Nasly and Yassin, 2009). Soils are variable and complex materials, whose properties can be modified to improve their performance in building construction through the addition of various stabilizers. The use of rice husk ash in the production of stabilized earth blocks present an alternative given the readily availability of rice husks in various rice processing factories in the country. The relative ease of manufacturing of the construction material is expected to reduce the cost of housing which may speed up the process of raising housing units. The main aim of this research study was to replace the relatively expensive cement with rice husk ash, as a stabilizer of interlocking earth blocks, which is a renewable resource in nature compared to the use of non-renewable cement as a stabilizer.

1.2.1 Need for alternative construction methods and materials.

The use of alternative cheaper materials as stabilizers would greatly enhance the production of affordable blocks with the desired properties. Presently cement and lime are used for soil stabilization which are relatively expensive options (Sanewu, 2013). There is thus the need for alternative binders that will reduce the cost of production and consequently the cost of construction works. The use of binders from by-products may be particularly advantageous, as the materials do not require 'mining', quarrying and processing as is the case with many of the conventional building materials. Rice husk ash is an agro-based product which may be used as a substitute of cement without sacrificing the strength and durability. The main aim of this research study was to investigate the performance of soil bricks stabilized using rice husk ash (RHA) and cement.

1.2.2 Soil availability

Soil is an earth material and it is readily available for construction purposes but due to its weakness, it requires great improvement of its properties before use. In the construction industry, clay soils have proved to be an engineer's nightmare because of their difficult in handling especially when they get wet. Walls made from mud swell and crack when exposed to alternate wet and dry weather (Narasihma et al, 2014). These are some of the factors that have made clay soil to be classified among the least suitable materials for construction. Consequently, large quantities of clay are dumped from construction sites annually while they could be utilized in construction through stabilization.

1.2.3 Cement stabilization

Cement has been used as an effective stabilizer for most types of soils, including clay soils. The main drawback of cement stabilization of clay soils has been the comparatively larger quantities of cement required. Rigassi (1985) found that about 5-6% cement was required when stabilizing other soils compared to 10-20% required for clay soils, thus raising the cost of stabilization of clay soils with cement. According to Walker (1995), compressed stabilized earth blocks creates 22kg of carbon dioxide per ton (CO_2/ton) compared to concrete blocks with 143kg of CO_2 per ton, fired clay bricks with 200kg of CO_2 per ton and aerated concrete blocks is 280-375kg of CO_2 per ton during production. Ordinary Portland cement (OPC) is not only expensive but environmentally unfriendly during manufacture. Production of one ton of OPC leads to the consumption of 1.5 tons of quarry material, energy consumption of 5.6 gigajoules per ton and an emission of nearly 0.9 tons of CO_2 representing 5 % of total anthropogenic CO_2 emission (Seco et al., 2012). Thus, there is need for environmentally friendly material to be developed to replace cement.

Rice husk ash is a pozzollanic material and is potentially useful in soil stabilization (Fattah *et al*., 2013). The pozzolanic material is readily available as an agricultural waste from various rice mills present in the country. The addition of pozzolans to cement or their use together with lime allow for the partial substitution or in certain applications full substitution of cement (Seco, et al., 2012). This has led to a reduction in the rice husk waste, energy consumption, emissions of CO_2 in cement production, production costs and improved engineering properties of stabilized clay soils.

1.3 Problem statement

The country's wide housing shortage has stimulated research for appropriate, easy, fast and cost-effective new ways of wall construction. Among many technologies found promising is mortar-less technology using interlocking stabilized earth blocks. Rice husk and clay from construction sites are wastes which may be utilized in the production of stabilized interlocking earth blocks which may lower construction costs and act as a way of waste disposal.

To solve the problem of inadequate housing and waste management, new construction materials must be considered and determined if they can provide a cheaper alternative to conventional building materials. Natural resources are being consumed at an increasing rate and it is important to consider alternative materials and processes for the production of building materials from these natural resources.

This study considers the use of a black cotton soil as waste from construction sites and rice husks a by-product of rice milling as potential construction materials.

1.4 Research questions

1. Can black cotton soil produce good quality stabilized earth blocks?
2. What is the minimum percentage of cement necessary for stabilizing black cotton soils for the production of earth blocks meeting required standard strength for building construction works?
3. Will the produced stabilized earth blocks be able to resist deteriorating environmental factors and how does the cost of earth blocks stabilized with rice husk ash and cement compare with the cost of cement stabilized earth blocks?

1.5 Objectives

1.5.1 Overall objective

The main objective of this study was to investigate the structural performance of rice husk ash and cement stabilized interlocking earth blocks for low cost housing in Kenya.

1.5.2 Specific objectives;

1. To establish the physical and mechanical properties of black cotton soil as a raw material for the production of stabilized earth blocks.
2. To determine the minimum percentage of cement necessary for stabilizing black cotton soils for the production of stable, cost effective earth blocks.

3. To determine the optimum amount of rice husk ash required to replace cement in production of affordable, stabilized earth blocks and assess the water absorption rate of the blocks under optimum strength conditions.

1.6 Study justification

The Universal Declaration of Human Rights of (UN, 1948) recognizes the right to adequate housing as an important component of the right to adequate living standards. Improvement of housing for the Kenyan population is a major concern to the Government that has been influenced by the fact that the improvement in housing stock is a strategically important social and economic investment. In addition, sustainable solid waste management enhances maintenance of a healthy, aesthetic, and ecologically sound environment. Most people either dump waste in open spaces or burn it, creating water and air pollution. Waste management involves waste collection, sorting, storage, recycling and disposal (Kaluli *et al,* 2011).

Ordinary Portland cement (OPC), the most commonly utilized and widespread binder produced in Kenya and the world, is becoming increasingly unaffordable for low-cost housing applications. The challenge of the need for a landfill for rice husk and clay soil disposal, air pollution through burning of bricks, overexploitation of fertile soil, high cost of transporting the unwanted clay material from the construction site to the dumping site and the need for sustainable low cost buildings to house people justify the need for more research to be focused on the structural performance of rice husk ash and cement stabilized interlocking earth blocks. The interlocking blocks do not require burning thus saving on wood fuel, no mortar is required to be laid during bricklaying work thus the process of building walls is faster and requires less skilled labor as the blocks are laid dry and lock into place. The interlocking earth blocks are environmental friendly as the materials used do not produce hazardous waste and emissions during their production.

1.7 Scope and limitations of the study

The research covered only the technical and economic analysis of cement and rice husk ash stabilized compressed clay soil blocks. The soil sample used was excavated from a construction site in Juja, Kiambu County. Rice husk ash was obtained from Mwea Tebere scheme millers which were burnt in uncontrolled temperatures.

The research was limited to getting soil sample from a single site, because of time and budget constraints. The husks also were burnt in uncontrolled temperature thus the quality of ash which had a lot of unburnt husks and carbon. Therefore this research study relied on the soil from Juja and the rice husk ash from Mwea Tebere scheme.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

According to K'Akumu (2004), Kenyan government has done little in keeping information pertaining to the state of the housing market. This has made it impossible for private investors to effectively address the growing demand for housing in the country. The statistical records which have aided in the improvement of housing in most developed nations are essential for Kenya to match up in her housing sector (K'Akumu, 2004).

Kenya has continued to develop infrastructural policy as a result of the institutional reforms brought about by the new constitution (Rabar and Wambu, 2010). For instance, the Kenya Vision 2030 provides a policy blueprint of the country's economic status by the year 2030. This may lead to the adoption of alternative materials for the construction of sustainable housing. However, much needs to be done to fight corruption as it poses the greatest impediment in the realization of this vision as it compromises the efficiency, effectiveness and the reach in service delivery. Watchdog groups such as Transparency International continue to rank Kenya poorly in dealing with corruption (Rabar and Wambu, 2010).

The materials utilized for soil stabilization such as lime and cement are industrially manufactured and they therefore keep construction costs higher. The practice of soil stabilization has enabled strengthening and increased durability of earth blocks. Increasing material costs in the construction industry has resulted in the need to find alternative construction materials. According to Nasly and Yassin (2009), the use of these alternative construction materials has the potential to lower construction costs as it will speed up the process of raising housing units.

Some of the materials already in use are the kiln fired bricks which are inexpensive as the raw material is dug from the ground near the construction site. Energy used to fire the bricks comes from firewood that may be collected near the construction site. The blocks are formed in a wooden or metal mold after which they are laid out to dry and later stacked in a kiln for firing (Parry, 1979). The firing increases the bonding strength between the particles (Stulz & Mukerji, 1993). The finished blocks are mostly irregular and thus the quantity of mortar required between the blocks and their dimensional inaccuracies make the building appear unattractive increasing the cost of construction in terms of cement usage.

Compressed and stabilized soil blocks have become a common choice when compared to the kiln fired bricks. This is because of their high wet compressive strength as the stabilization and procedure of compaction removes voids in the finished block. The increase in density results in higher compressive strength and a reduction of potential ingress of moisture in the block (Norton, 1997). In addition, cement and lime have been introduced as chemical stabilizers in binding the particles together. However, these additives are expensive.

Sanewu (2013) studied the use of animal dung and municipal solid waste ash (MSWA) as alternative stabilizer for clay blocks and reported that addition of 2% municipal solid waste ash and 5% animal dung ash gave the blocks the highest compressive strength after 28 days. For the unstabilized blocks, the compressive strength was higher after 7 days and decreased after 28 days. He concluded that the increase in strength for the 2% MSWA stabilized blocks was due to the pozollanic ash reaction.

2.2 Rice husk ash

2.2.1 Properties of rice husk ash (RHA)

Rice husk ash (RHA) is potentially useful in soil stabilization (Fattah *et al*., 2013). The pozzolanic material is readily available as an agricultural waste from various rice mills present in the country.

RHA is a very fine material. The average particle size of rice-husk ash ranges from 5 to 10μm (Hisham *et al* 2012). The production of RHA involves burning of the rice husk under controlled temperature. This leads to the production of ash that is approximately 17%-25% of the rice husk's weight (Fattah et al., 2013). The silica contained in RHA is in amorphous form meaning it can readily react with the $Ca(OH)_2$ that is liberated during hardening of cement to form a cementatious compound (Oyetola and Abdullahi, 2006).

Rice husk ash is a pozzolan, which contains as much as 80-85% silica that is highly reactive, depending on the temperature of incineration (Kishore et al, 2011). Pozzolanas are defined as siliceous and aluminous materials which in themselves possess little or no cementing property, but will in a finely dispersed form in the presence of water chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementing properties. When water is added to a mixture with pozzolanic material, the resulting product which acts as cement in some instances provides a stronger bond than cement alone (Nick, 2009).

The characteristics of the ash are dependent on the components, temperature and time of burning (Nick, 2009). During the burning process, the carbon content is burnt off and all that remains is the silica content. The silica must be kept at a non-crystalline state in order to produce an ash with high pozzolanic activity. It has been tested and found that the ideal temperature for producing such results is between 600 °C and 700 °C (Nick, 2009).

If the rice husk is burnt at too high temperatures or for too long, the silica content becomes a crystalline structure. If the rice husk is burnt at too low temperature or for too short a period of time the rice husk ash will contain too large amounts of un-burnt carbon. Carbon does not possess pozzolanic properties, thus it does not take part in the strength development process. It acts more or less as filler (Nick, 2009).

The chemical composition for pozollanas as stipulated (ASTM C618, 2003) should be met by rice husk ash chemical properties. The combined proportion of silicon dioxide (SiO_2), aluminium oxide ($A1_2O_3$) and iron oxide (Fe_2O_3) in the ash should be not be less than 70%, and loss of ignition (LOI) should not exceed 12% as stipulated in ASTM requirement (Hisham et al, 2012).

Table 2–1 gives physical composition of RHA by various researchers (Hisham et al, 2012).

Table 2-1: Physical properties of RHA

Property	Mehta et al	Zhang et al	Bui et al
Mean particle size (µm)	-	-	5.0
Specific gravity	2.06	2.06	2.10
Fineness: Passing 45 µm (%)	99	99	-

Table 2-2 below shows the chemical composition of the Kenyan rice husk ash samples from Mwea and Ahero (Kamau, et al, 1993).

Table 2-2: Chemical composition of RHA from Mwea and Ahero

CONSTITUENT	PERCENTAGE BY WEIGHT (%)	
	Mwea	Ahero
SiO_2	85.00 ± 1.47	89.44 ± 0.52
Fe_2O_3	0.23 ±0.06	0.41 ±0.02
Mn_2O	0.12 ±0.01	0.14 ±0.01
MgO	0.43 ±0.12	0.42 ±0.31
Ca	0.67 ± 0.30	0.58 ±0.05
Na_2	0.07 ± 0.02	0.47 ± 0.08
AlO_3	0.32 ± 0.08	0.46 ± 0.11
K_2O	1.24 ± 0.29	1.35 ± 0.08
P_2O_5	0.71 ± 0.42	1.55 ± 0.25
Loss on ignition	6.93 ± 1.33	3.66 ± 0.06
Total %	95.72 ± 1.25	98.48 ± 0.41

Source: Kamau, et al, 1993

Research on the potential of using rice husk ash reveals that some of its physical properties (larger specific surface area; fine particle size; etc. (Obam *et al*, 2011) are responsible for the role that rice husk ash plays in improving the material properties and durability. Table 2-1 shows some physical properties of RHA.

2.2.2 Behaviour of RHA

The chemistry of rice husk ash involves the chemical reactions of the amorphous silica in the ash with cement to form calcium silicate hydrates. Reactions that take place in the preparation of rice husk ash concrete are given below using hypothetical equations. Silicon burnt in the presence of oxygen gives silica.

$$Si + O_2 \text{ -------- } SiO_2$$

Hypothetical equation for the hydration of cement is as shown below:

$$C_3S \text{ (Cement)} + H_2O \text{ ----------- } CSH + Ca(OH)_2$$

The highly reactive silica reacts with calcium hydroxide released during the hydration of cement, resulting in the formation of Calcium Silicate Hydrate, which is responsible for strength (Kishore et al, 2011).

$$SiO_2 + Ca(OH)_2 \text{ ----- } CSH + SiO_2$$

Above reactions are also valid for stabilizing soil with lime and RHA. In that case, calcium hydroxide is generated by reacting lime and water instead of hydration of cement.

2.3 Black cotton soil

Clay is a naturally occurring aluminium silicate primarily composed of fine-grained minerals. Clay deposits are mostly composed of clay minerals, a sub-type of phyllosilicate minerals, which impart plasticity and harden when fired or dried. They also may contain variable amounts of water trapped in the mineral structure by polar attraction (Houben and Guillaud, 1994). Organic materials which do not impart plasticity may also be a part of clay deposits. Clay is the common name for a number of fine-grained, earthy materials that become plastic when wet (Namango, 2006).

Clay soils have been classified into 3 basic types (Namango, 2006):

- **Kaolinite** - This is a type of clay that has very stable minerals and is among the last formed in the weathering process. It exhibits very little physio-chemical activity compared to other clay minerals, because of a comparatively large grain size and low surface charge.
- **Illite –** This exhibits intermediate physio-chemical activity. Their inter-layer potassium ions form a weak ionic bond with the oxygen ions in the silica sheets. A deficiency of potassium results in greater unsatisfied valence charge and correspondingly greater activity. Occurrence of Illite is common in clay minerals.
- **Montmorillonite** - These are the most troublesome when abundant water is present and are the most claylike (active) of the clay minerals. Montmorillonites are very unstable chemically and are among the initially formed products of chemical weathering of parent rocks. They derive principally from volcanic parent materials in a moist environment. Black cotton soil falls in to this category of clays.

General properties of clay minerals include plasticity when mixed with water in certain proportions, shrinkage under firing and air drying, fineness of grain, high cohesion, and capacity of the surface to take decoration. Depending on the content of the soil, clay can appear in various colours, from a dull gray to a deep orange-red (Katti, 1979).

2.3.1 Normal range of properties of black cotton soils

The range of variation of index, engineering and chemical properties of Black cotton soils are tabulated in Table 2-3 and 2-4 (Katti, 1979).

Table 2-3 Normal range of properties of black cotton soils

S. No.	Description	Average range of values
1	Specific gravity	2.7-2.9
2	Liquid limit (%)	40-100
3	Plastic limit (%)	20-50
4	Shrinkage limit (%)	8-18
5	Plasticity index (%)	20-50
6	Maximum dry density (Kg/m^3)	1300-1700
7	Optimum moisture content (%)	18-30
8	Colour	Dark grey to black
9	Free swell index (%)	70-300

Source: Katti, 1979

Table 2-4 Normal range of chemical properties of black cotton soils

S. No.	Description	Formula	Range
1	Silica	SiO_2	48-58(%)
2	Alumina	Al_2O_3	13—22(%)
3	Lime	CaO	1-8(%)
4	Magnesium oxide	MgO	1.8-5.0(%)
5	Ferric oxide	Fe_2O_3	7.5-1.5(%)
6	Sulphates	SO_4	0.9-2.0(%)

Source: Katti, 1979

2.3.2 Clay in construction: The challenge

Clay is one of the oldest building materials on earth, among other ancient naturally-occurring geologic materials such as stone and organic materials like wood. Between one-half and two-thirds of the world's population in traditional societies as well as developed countries still lives or works in a building made with clay as an essential part of its load-bearing structure (Namango, 2006). Also a primary ingredient in many natural building techniques, clay is used to create adobe, cob, cordwood and rammed earth structures.

Clays exhibit generally undesirable engineering properties (Brooks, 2009). The main problem associated with clay as a construction material is its shrink-swell property. Due to the physical and chemical properties of some clay, large swelling occurs when water is absorbed. Conversely, when the water dries up, these clays contract or shrinks (Narasihma *et al*, 2014). This poses a serious challenge in construction. Depending upon the supply of moisture in the ground, shrink-swell soils will experience changes in volume of up to thirty percent or more. Foundation soils which are expansive will “heave” and can cause lifting of a building or other structure during periods of high moisture (Koteswara *et al.* 2011). Conversely during periods of falling soil moisture, expansive soil will “collapse” and can result in building settlement. Either way, damage can be extensive.

According to Namango, (2006), when clay soils are used to make earth blocks for construction of walls, the alternate expansion and contraction of the soil accelerates the wearing out of the walls resulting in a shorter life span. This occurs through surface cracking of walls and their consequent erosion, which may eventually lead to structural failures. Movement often causes the crumbling of surface coatings.

The magnitude of the challenge associated with clay varies with climate and the use to which the clay soil has been put, but light weight buildings generally tend to be more prone to damage (Houben and Guillaud, 1994). Some common preventative measures that may be used to minimize damage related to clay construction include:

- Extending the foundations to greater depth.
- Use of extra reinforcing steel to foundations and slabs.
- Drainage of the surface and/or subsurface water
- Pre-moisturizing of the soils prior to construction
- Providing non-expansive material
- Treatment of the soils with additives such as lime, fly-ash and other chemicals

2.4 RHA utilization in past research studies

Muntohar (2002) reported that there is a potential use of silica waste, resulting from burnt rice husk, as a pozzolanic material. He studied the utilization of ashes produced from uncontrolled rice husk burnt in Yogyakarta (Indonesia). Atterberg limits, compaction, compressive strength and bearing capacity tests were carried out individually or in a combination in which the rice husk ash (RHA) content varied from 7.5, 10, and 12.5 percent, and lime content from 2, 4, 6, and 10 percent (by the dry weight of soil). He found that lime – rice husk ash decreased the swell of expansive soil and improved its strength and bearing capacity.

Mtallib and Bankole (2011) carried out experimental study on lime stabilized lateritic soils using rice husk ash as admixture. The index property tests classified the soils as A-7-6 under the AASHTO soil classification scheme. Index and geotechnical properties tests conducted on the soil containing lime and rice husk ash combinations showed significant improvement in properties. The Atterberg limits were significantly altered with lime and rice husk ash combination; the plasticity of the soils were significantly reduced from 18.10 to 6.70 for soil sample A and 26.6 to 5.92 for soil sample B at 6 % lime and 12.5% RHA combination. In terms of compaction characteristics, addition of lime and rice husk ash decreased the maximum dry density and increased the optimum moisture content. At 8% lime and 12.5% RHA, the values of MDD for soil samples A and B were 1.27 and 1.22 Mg/m^3 respectively. The California bearing ratio values peaked at 50% unsoaked values for 8 % lime and 10 % RHA combinations for soil sample A while that of soil sample B was 30% at 6% lime and 12.5% RHA combinations. They found that the material is deemed inadequate for use as a road pavement base or sub-base.

Koteswara *et al.* (2011) used rice husk ash, lime and gypsum as additives to expansive soil which resulted in considerable improvement in the strength characteristics of the expansive soil. It was found that rice husk ash could potentially stabilize the expansive soil solely or mixed with lime and gypsum. The utilization of industrial wastes like RHA, lime and gypsum is an alternative to reduce the construction cost of roads particularly in the rural areas. It was observed that the liquid limit of the expansive soil decreased by 22% with the addition of 20% RHA and 5% lime. It was noticed that the free swell index of the expansive soil had been reduced by 88% with the addition of 20% RHA and 5% lime. The unconfined compressive strength of the expansive soil had been increased by 548% with addition of 20% RHA and 5% lime and 3% gypsum after 28 days curing. The research also found out that rice husk ash had the potential to stabilize soil on its own.

Shah *et al* (2013) studied the use of rice husk ash as a stabilizer in rammed earth. The proctor tests results indicated that with the increase in RHA percentage there was an increase in the optimum moisture content (OMC) from 9.84% to 19 % and reduction in the maximum dry density (MDD). The compressive strength values decreased with increase in percentages of rice husk ash addition and having its maximum strength at 5% RHA.

Sabat *et al* (2011) studied the effect of marble dust on strength and durability of rice husk ash stabilized expansive soil and found that the optimum percentage of rice husk ash was 10% based on unconfined compressive strength and marble dust was added. The soaked California Bearing Ratio (CBR) tests and unconfined compressive strength test of the RHA stabilized expansive soil increased up to 20% addition of marble dust. They also noted that further addition of marble dust had negative effects on these properties. The durability test showed that the addition of marble dust made the rice husk ash stabilized expansive soil durable. They concluded that for best stabilization effect the optimum proportion of soil: rice husk ash: marble dust was 70: 10: 20.

Sarkar *et al* (2012) studied the effects of rice husk ash (RHA) on the geotechnical properties of cohesive soil in stabilized forms specifically strength, workability, compaction and compressibility characteristics. They carried out laboratory tests for different percentages of RHA content and original soil samples. They found that the soil could be made lighter in weight which led to decrease in dry density and increase in moisture content and reduced free swelling and compressibility due to the addition of RHA with the soil. Besides that the unconfined compressive strength and shear strength of soil can be optimized with the addition of 10% RHA content.

Obam *et al* (2011) studied the engineering properties of clay-rice husk ash composites. They carried out laboratory experimental procedures to determine the specific gravity of the clay, plasticity index, strength, shrinkage, cracks, and weight of natural clay mixed with rice husk ash (RHA). Results showed that the average specific gravity of the clay was 2.65; shrinkage, plasticity, and cracking of the clay were improved in the composites. However, the compressive strength of clay was not improved by the addition of RHA.

Eberemu (2011) conducted one dimensional laboratory consolidation tests on compacted lateritic soils treated with up to 16% rice-husk ash (RHA) to assess its consolidation properties. Specimens were prepared at three different moulding water contents (2% dry of optimum, optimum moisture content (18%) and 2% wet of optimum) and compacted using the British Standard Light compactive effort. Pre-consolidation pressure increased with RHA content; it also decreased before increasing with increased moulding water content. Reductions in compression index (Cc) and swell index (Cs) with increased RHA content were recorded. Cc and Cs generally decreased before increasing with increased moulding water content. The coefficient of volume compressibility (Mv) decreased and later increased with higher

RHA content; they were also affected by the soil particle state with increasing pressure. The co-efficient of consolidation (CV) showed no observable trend with increased RHA content but generally increased with higher consolidation pressure on the dry and wet side of optimum compacted states.

Jain and Puri (2013) conducted one-dimensional consolidation tests to study the effect of addition of various percentages of rice husk ash on compressibility characteristics of highly plastic clay soil. It was observed that due to the addition of rice husk ash to the parent clay, compression index (Cc) decreased significantly with increase in percentage of rice husk ash, hence decreasing consolidation settlement of parent material. It was also observed that the time required for achieving a given degree of consolidation decreased with increase in the percentage of rice husk ash at a particular effective stress. In general, it was observed that rice husk ash effectively increased one-dimensional stiffness and therefore, reduced settlement.

Narasihma *et al* (2014) conducted compressibility behaviour of black cotton soil admixed with lime and rice-husk ash and found that optimum moisture content increased as the percentage of lime or RHA or lime and RHA increased. Maximum dry unit weight decreased as the percentage of lime or RHA or lime and RHA increases. 1:1 mix ratio is more effective than all other ratios investigated indicating extra pre-consolidation effect to the soil and economical among all the other ratios in reducing compression index. Compression index and swelling index of the soil decreased as the percentage of admixture increased while coefficient of stability increased. Coefficient of consolidation decreases as the consolidation pressure increases and as the percentage admixture increases. Hence the compressibility characteristics of black cotton soils could be improved to a great extent by stabilizing either with lime or lime and rise-husk ash in combination in 1:1 proportion. They also concluded that the secondary additive rice-husk ash not only brought down the cost of stabilization but also appeared to be a successful solution for improving the engineering properties of black cotton soils .Thus economy in stabilization can be achieved.

However, from the reviewed literature (Shah *et al*, 2013, Muntohar, 2002, Mtallib and Bankole, 2011, Koteswara *et al.*, 2011, Sarkar *et al*, 2012), the previous works with RHA have shown that it has promising potentials of improving the engineering properties of soils for sub-grade and walling purposes. Thus, this work focused on investigating the performance of compressed interlocking soil blocks stabilized using uncontrolled burnt rice husk ash (RHA) and cement.

2.5 Research gap

This research was being carried out with the concern of reducing energy usage and the consequent CO_2 emissions arising from firing clay bricks in kilns and during cement production which has a direct effect on climate change (CERAM, 2009). Fired clay bricks requires cutting down of trees to be used in burning them. This causes increased deforestation and can lead to drought which may expose homes and occupants to greater risks unless this is reduced. The fact that rice husk ash soil stabilized earth blocks (unfired clay bricks) are unburned and can be manufactured onsite and used without any transport cost, makes them a cheap material with very low embodied energy. In today's climate where energy prices and environmental awareness of the general public is on the increase, research on stabilized earth blocks is considered to be a significant contribution to knowledge. Their use is a cost effective opportunity for locals to have better houses while reducing deforestation.

From the reviewed literature, existing research studies on compressed interlocking blocks using black cotton soil for building applications are relatively few when compared to the volume of research completed on clay fired brick development. From the reviewed existing literature, it is realized that there are still some particular drawbacks such as high manufacturing costs, high product costs, the use of large proportion of cement in stabilizing the soil and mortar for joining the soil blocks. In general, from all the stabilization techniques there have been no reported cases of compressed interlocking blocks technology i.e. production of unfired clay bricks with black cotton soil and rice husk ash as a main stabilizing agent. Consequently it can be acknowledged that the current research work is a new idea of incorporating activated rice husk ash waste material in soil stabilization.

On the other hand, from the reviewed literature, the utilization of rice husk ash, an agricultural by-product, is ingrained as a binder in many concrete applications in other countries like India and UK. It has been utilized for soil stabilization in highways and other foundation layers, where it has been claimed to provide enhanced durability, improve the engineering properties, control the volume stability, and increase the resistance to erosion, weathering and traffic loading.

Rice husk ash has extremely low energy usage and CO_2 emission when compared with cement and this make it a good material which can be utilized to partially replace cement thus reducing the environmental effects and save energy in cement production. The local availability of rice husks in some rice producing counties in Kenya means that the rice husk ash utilization in this research work is in line with the current sustainability guidelines for new material development in Kenya and in the world at large.

This research was hoped to contribute to existing knowledge on compressed earth blocks produced with black cotton soil, by utilizing the promising cementitious properties of rice husk ash to improve the black cotton soil in terms of strength and durability and also produce cost effective materials for construction walls thus providing decent and low-cost housing.

3 CHAPTER THREE: MATERIALS AND METHODS

3.1 Acquisition and processing of stabilizers

Rice husk is an agricultural residue from the rice milling process. Rice husks used in the preparation of rice husk ash used in the experimental study were obtained from Mwea Tebere rice scheme millers. The ash was sieved through 0.6mm sieve to remove unburnt particles and then finally sieved through 150µm sieve to get the fine ash used.

Cement used was ordinary Portland cement (OPC) (Kenya Bureau of Standards KS-02:l976) from Bamburi cement factory. OPC was selected because it has a unique and superior binding capacity, and also, it is widely available in most parts of the country and the world at large. Lime is inexpensive, but care must be taken to protect workers from breathing in lime dust (Kerali, 2000).

3.2 Preparation of experimental soil

Black cotton soil was collected from a construction site within Jomo Kenyatta University of Agriculture and Technology. To obtain a soil sample, about 200 mm of the top soil layer was removed and then the sample was scooped. This was done to avoid excessive organic matter from the top soil layer. The collected sample was then air dried. Due to the nature of soil which contains various sizes of grain from very fine dust up to pieces that are still too large for use in block making, the oversized material was ground and others removed by sieving using a 5 mm sieve manually in accordance to the procedure outlined in BS 1377-1:1990.

3.3 Determination of physical and mechanical characteristics of soil

The following geotechnical properties were determined: Particle Size Distribution, specific gravity and Atterberg Limits in accordance to BS 1377-2:1990 procedures and standards. Compaction characteristics of the soil (Maximum Dry Density and Optimum Moisture Content) were determined in accordance to the BS 1377:1990: Part 4 procedures and standards.

Figure: 3-1 Standard proctor compaction test

3.4 Preparation of stabilized soil and production of interlocking earth blocks

3.4.1 Stabilization with cement

Cement was added to black cotton soil for purposes of stabilization. Quantities of cement were varied as shown in Table 3-1. The dry soil and cement were thoroughly mixed, and then water was added a little at a time until the optimum moisture content of the mixture was reached. Three (3) interlocking blocks were made for the compressive strength tests after 7, 14 and 28 days of curing using each of the five categories of cement content.

Table 3-1: Mix proportions for cement

Batch No.	1	2	3	4	5
Cement (%)	0	6	8	10	12

The soil blocks were made using a CINVA-Ram press machine which was manually operated and blocks extruded immediately.

Figure: 3-2 Batching, mixing and blocks production

The blocks were then cured in the shade and kept covered with polythene to slowly while being cured.

Figure: 3-3 Blocks curing in a shade and later covered with polythene

The interlocking block sizes produced were 230mm long, 225mm wide and 130mm high. The results were then analyzed to determine the minimum amount of cement necessary to stabilize black cotton soil for the production of interlocking earth blocks with the minimum required compressive strength of 2.5MPa (KS 02-1070: 1993).

3.4.2 Stabilization with rice husk ash (RHA) and cement

Standard compaction proctor test were conducted on soil stabilized with different proportions of cement and RHA as shown in Table 3-2. Compaction was carried out using mechanical compaction test equipment with a 2.5 kg rammer falling through a height of about 30 cm. The soil was compacted in three layers, each receiving 27 blows. This was carried out to realize the optimum moisture content (OMC) required in mixing the soil used to produce earth blocks.

Table 3-2: Mix proportions for cement and rice husk ash

Batch	Cement (%)	RHA (%)
1	8	0
2	7	2.5
3	6	5
4	5	7.5
5	4	10
6	3	12.5
7	2	15
8	1	17.5
9	0	20

For each mix twelve replicates were produced. Three blocks were tested for compressive strength after 7, 14 and 28 days of curing, respectively. Water absorption test was done for three blocks.

3.5 Compressive strength and water absorption of interlocking earth blocks

3.5.1 Dry compressive strength test of interlocking earth blocks

Compressive strength tests were conducted using a universal testing machine and the data recorded using a data logger with a sensitivity of 2.0Mv/V and a load cell with a capacity of 50 tonnes. The block to be tested was loaded across the full width and breadth. Special steel plates of sizes 100mm x 240mm with slanting edges, 50mm x 240mm with a slanting side and thickness 10 mm were prepared and placed within the grooves of the blocks as shown in Figure 3-1. The plates were welded on a flat steel plate to ensure they interlocked well with the grooves of the block. This type of loading method is set to simulate behavior of blocks in practice, where blocks are laid in an interlocking tongue and groove manner and all voids are filled with mortar

(Deepak, 2010). The load was applied gradually over the plates till failure occurred. The maximum load at failure was noted. The dry compressive strength of each specimen is then calculated using the formula:

$$C_D = \frac{W_D}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where:

C_D = Dry compressive strength in N/mm^2.

W_D = Total load at which the dry specimen failed in Newton's.

A = the surface area on which the load was applied in mm^2

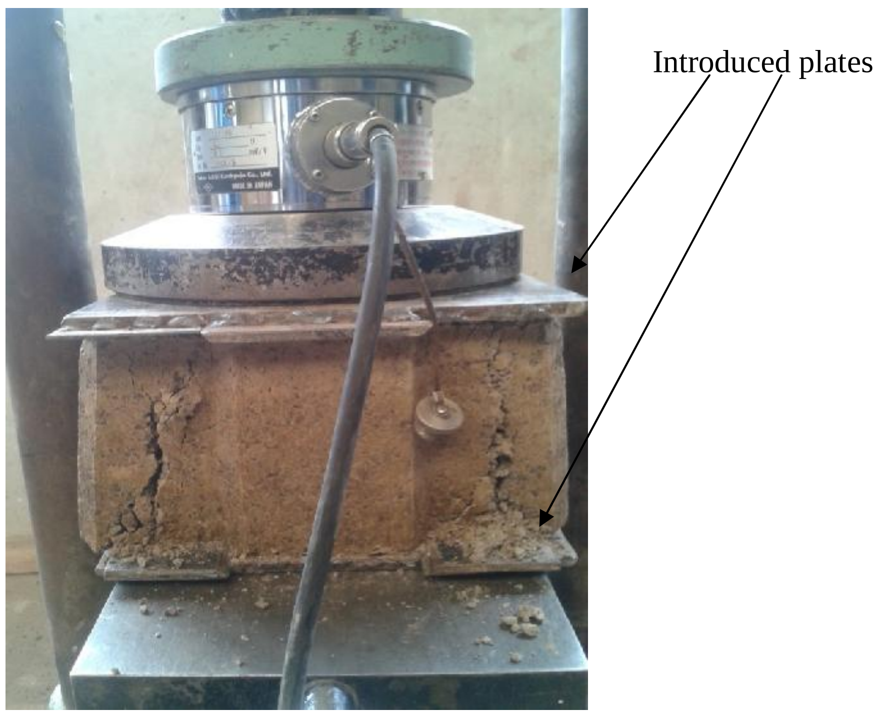

Figure: 3-4 Compressive strength test of the blocks

The compressive strength of the block (C_D) was then calculated and the raw is as shown in appendix ix and xiii. This test was done after curing the blocks for a period of 7 days, 14 days and again at 28 days.

Various international standards exist to govern the minimum permissible compressive strength of soil stabilized blocks. German Standard DIN 18954 recommends a minimum compressive strength between 2 and 4 MPa (Minke, 2006) for dry soil stabilized blocks, while New Mexico Earthen Building Materials Code Section 14.7.4.23 requires a minimum compressive strength of 300 psi (2.06 MPa) for soil stabilized blocks that have been fully submerged in water for a minimum of four hours. Both the above standards limit soil stabilized block buildings to two stories. Based on these standards, a minimum compressive strength of 2.5 MPa was chosen as a mix design evaluation criteria. The minimum amount of cement stabilizers required were obtained by using a linear graph on the 28th day compressive strength values.

3.5.2 Water absorption of interlocking earth blocks

Using an electronic weighing machine, dry blocks were weighed (W_d) and, immersed in water for 24 hours, after which they were removed and weighed again (Ww). Only 5 mm of a block was inserted in water.

Figure: 3-5 Water absorption test of the blocks

The percentage moisture absorption by weight was calculated as follows:

$$Mc = \frac{Ww - Wd}{Wd} \; x \; 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where:

Mc = percentage moisture absorption (%)

W_w= mass of wetted sample (g)

W_d = mass of dry sample (g)

The resulting value was analyzed in tabular and graphical format to understand the relationship between the stabilizer and the water absorption.

3.6 Unconfined compressive strength for the experimental soil

Soil stabilized with different amounts of cement was used in this study to prepare the specimens (See Table 3-1). Cylindrical soil specimens of 50 mm diameter and a height of 100 mm were molded as shown in figure 3-2 and cured for 7 days in a moist environment before subjecting them to compression test. An average of three specimens per mix was tested for unconfined compressive strength, in accordance with BS 1924-2; 1990, using a compression machine.

Figure 3-6 Unconfined Compressive strength test

The deformation indicator was adjusted to zero point as the initial reading of the electronic deformation device. The load was then applied so as to produce an axial strain at a rate of 1 mm/min. The deformation dial reading was recorded at intervals of 20 and the corresponding load dial reading was also recorded. The specimen was loaded until the load values decreased, indicating specimen failure. The mean strength of the three test specimens was determined as the representative strength for a particular mix composition. The dial readings were converted to the appropriate load and length units and data presented in appendix X.

A graph of load per unit area (ordinate) versus unit strain (abscissa) was prepared as shown in appendix X. From this graph, the unconfined compressive strength, q_u, was evaluated as either the maximum value of load per unit area or the load per unit area at 15% strain, whichever occurs first.

3.7 Linear shrinkage test for the interlocking blocks

The dimensions of the interlocking block were measured when dry before testing them to get the dimensional changes from wet to dry cured blocks. A vernier calliper was used to measure the dimensions of the blocks and test results are shown in table 4-8. The linear shrinkage was then calculated as:

$$\% \, Linear\ shrinkag \; = \frac{\Delta L}{L} \, x \, 100 \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3.3$$

Where: ΔL = Change in length of the block

L = Original length of the block

The results were recorded in tabular for and analyzed in a bar graph format.

3.8 Cost analysis

The cost of using rice husk ash and cement to stabilize clay for earth block production was compared against the cost of soil stabilization using cement. This was carried out upon determining the minimum amount of cement and mix proportion of cement and rice husk ash required for stabilizing black cotton soil for the production of interlocking earth blocks which meets the minimum required compressive strength.

4 CHAPTER FOUR: RESULTS, ANALYSIS AND DISCUSSION

4.1 Physical properties of the soil sample

The physical and mechanical properties of the soil sample were considered as they are of greater interest for making compressed stabilized soil block. The results of these properties will help to determine the ease of mixing, forming, de-molding, shrinkage, dry strength and apparent bulk density of the blocks.

4.1.1 Particle size distribution

A combined analysis of particle size distribution was used to determine the soil grain size. Wet and dry sieving analysis was carried out where by the soil was shaken mechanically through a stack of sieves with different opening sizes and the percentage retained in each sieve recorded. The particles smaller than sieve 0.075mm were analyzed by using a hydrometer and Stoke's equation for the velocity of a free falling sphere to determine the range of fine particles. The results of these tests are shown in (Appendix I) and plotted in Figure 4-1.

From Figure 4-1, there was 12.82% gravel, 7.92% sand and 79.26% fines (silt + clay) in the soil. According to Rigassi (1985), the range of particle distribution suitable for building of earth block is: 0 – 40% gravel, 25 - 80% sand and 18 - 55% fines (silts and clays). This implies that the study soil sample from Juja construction site did not fulfill these requirements and thus not suitable for earth block production. In other words, the soil studied required an improvement or stabilization for it to be utilized in block production.

From the overall geotechnical properties of the soil, it was classified as A-7-5 in the AASHTO classification system. The soil can also was also classified as silt and clays category of CH (inorganic clays of high plasticity, fat clays) according to Unified Soil Classification System (USCS). The grading curve of the soil did not permit the derivation of the grading characteristics which could be further used for soil classification by USCS.

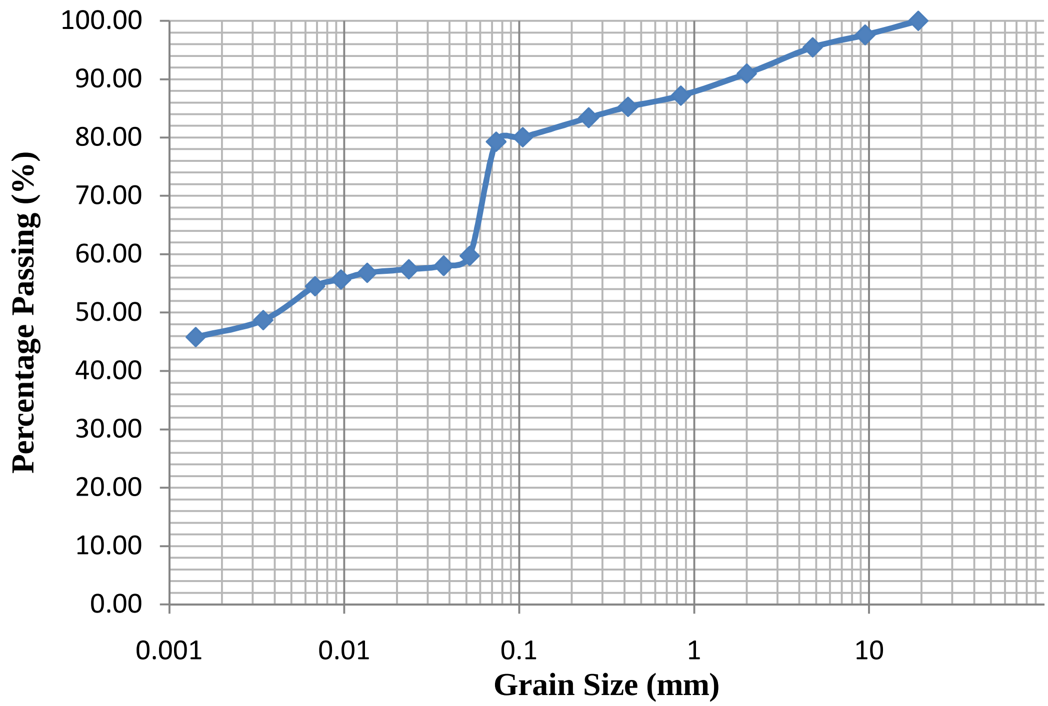

Figure 4-1 Particle size distribution of the soil sample

4.1.2 Specific gravity

The specific gravity raw data values of the test soil samples are shown in appendix II and tabulate in table 4-1. The average specific gravity of the black cotton soil is 2.55. Bowles's (1997) gave specific gravity for cohesive soils containing clay, silt and sand to be between 2.68-2.75. The specific gravity result of 2.55 could have been as a result of the presence of organic matter or humus in the soil sample. This implies that the soil sample used might have mixed up with the organic matter during the collection and preparation. However, this will not have any effect in the preparation and the strength of the interlocking blocks.

Table 4-1 Specific gravity for the black cotton soil

Particle Density	g/cm^3	2.547	2.554	2.549
Average Particle Density (g/cm^3)			2.550	

4.1.3 Atterberg limits

The Atterberg limits tests define the moisture content at which the soil passes from a liquid state to plastic state and from plastic state to a solid state; these boundary points are the liquid and plastic limits respectively. The tests were carried out on the soil sample and with different proportion of cement. Atterberg limit test results are given in appendix III and in Table 4-2.

Figure 4-2 shows the effect of cement in the soil on Atterberg limits. It can be seen that liquid limit decreased and plastic limit increased with the increase of cement content in the soil. Reduction in liquid limit of the soil is drastic from 6% to 10% cement content. From 10% to 12% cement content, there is no significant change in liquid limit. Flocculation in the mixture was not significant from 6% to 10% cement content leading to a significant decrease in liquid limit. Plastic limit also increased considerably from 6% to 8% cement content where it started decreasing. The decrease in plastic limit was not considerable as it became significantly constant. Floccules formation was high for 6% to 8% cement content and it had a great effect on the plastic limit increase. For 10% and 12% cement content, the floccules formed did not have a significant effect. Behmanesh and Mehrmousavi, (2014) also obtained similar results using cement as a stabilizer for clayey soil.

Table 4-2 Atterberg limit test results of soil samples

Mixes	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)
Black cotton soil (BCS)	90.25	32.44	57.81	16.14
BCS + 6% cement	84	47.6	36.4	14.79
BCS + 8% cement	79.13	49.93	29.2	12.82
BCS + 10% cement	76.2	48.16	28.04	11.54
BCS + 12% cement	75.32	47.75	27.57	9.68

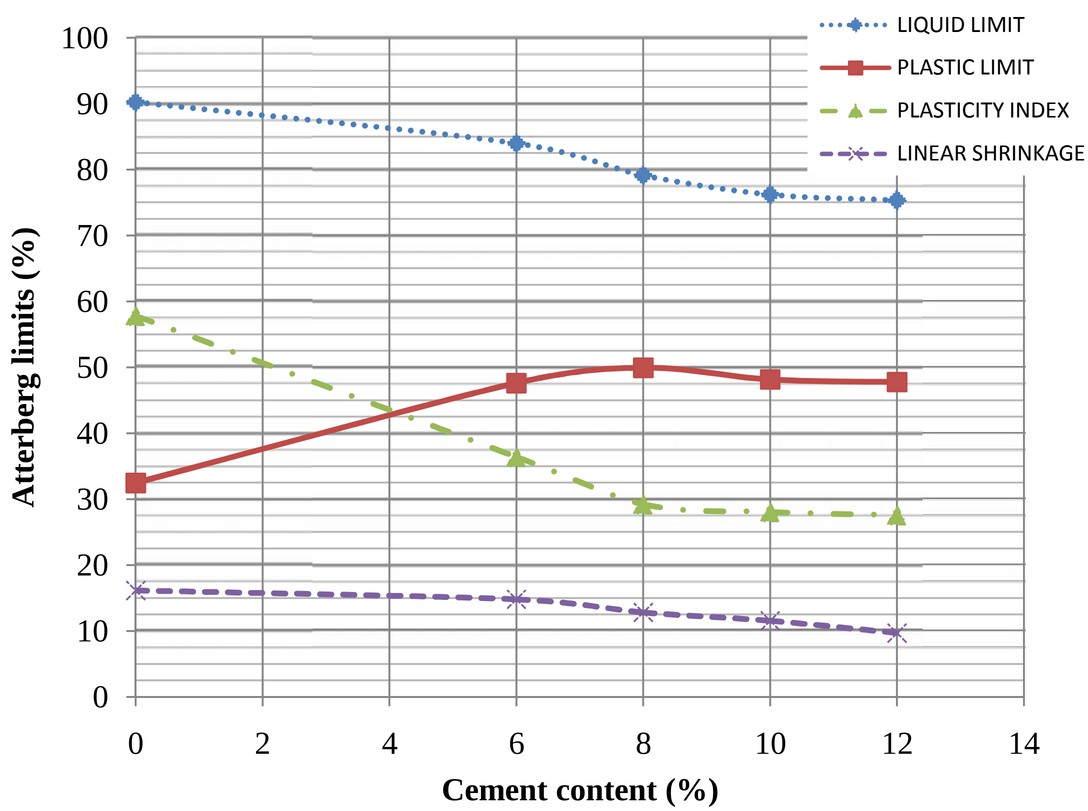

Figure 4-2 Effect of cement content on Atterberg limits

Plasticity index and linear shrinkage decreased with an increase in cement content. A drastic decrease plasticity index is seen for 6% and 8% cement content and constant decrease for 10% and 12% cement contents. Linear shrinkage had a constant decrease for all the cement content increases. This meant that floccule numbers did not have significant change when cement content was more than 10% because the liquid limit, plastic limit and plasticity index were nearly constant. The unstabilized soil sample had 90.25% liquid limit, 32.44% plastic limit, 57.81% plasticity index and 16.14% linear shrinkage. The greater PI becomes, the greater the swell when soil is moistened and its shrinkage when it dries.

4.1.4 Maximum dry density – moisture content relationship

The general meaning of soil compaction in soil mechanics is to press soil particles tightly together by expelling the air from void spaces between the particles. It is also a cheap and effective way to improve the properties of a soil sample. The amount of compaction is quantified in terms of dry density (dry unit weight) of the soil.

Appendix IV to VIII shows the compaction test results for soils with various percentages of cement. A graph of dry density versus moisture content was drawn to determine the effect of cement on the compaction characteristics of the black cotton soils.

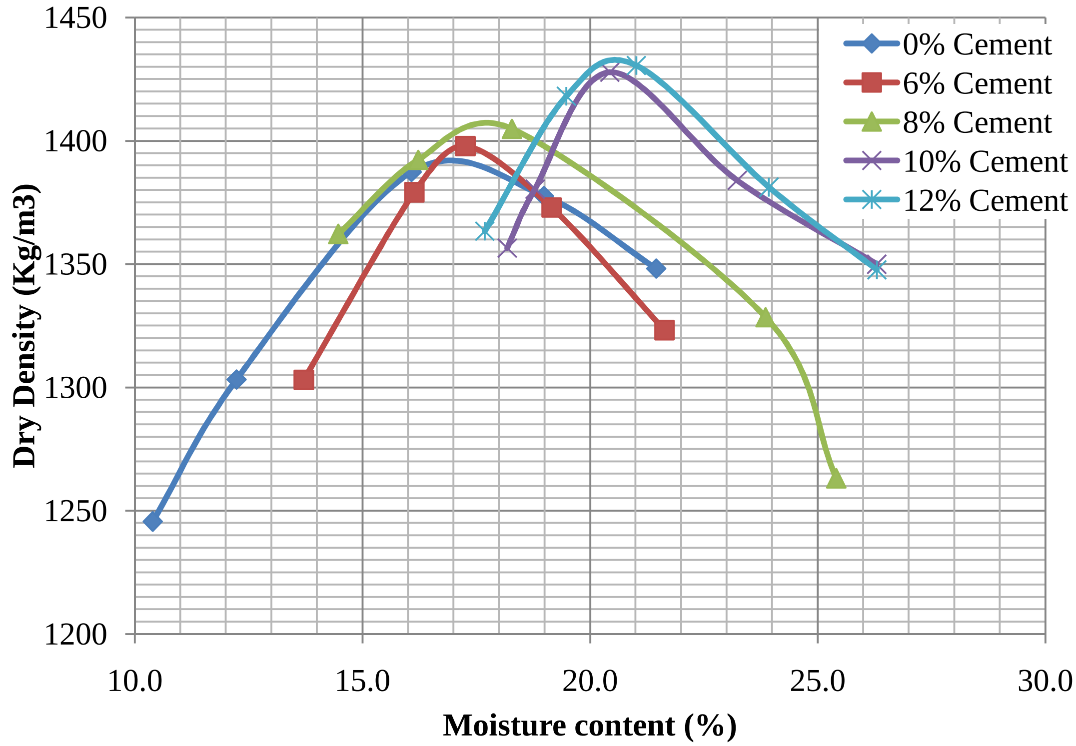

Figure 4-3 Variation of dry density with moisture content

From figure 4-3, the maximum point or the peak of each line graph was used to get the MDD and the OMC of the soil sample. The results are as shown in table 4-3.

Table 4-3 Compaction Tests analysis

Compaction Tests analysis		
% stabilizer	MDD (Kg/m^3)	OMC (%)
0	1382	15.8
6	1398	17.2
8	1408	17.8
10	1428	20.3
12	1439	21.6

The results from table 4-3 were used to generate the relationship between the stabilizer content with MDD and OMC respectively. These variations of MDD and OMC with stabilizers contents are shown in Figure 4-4 and figure 4-5 respectively.

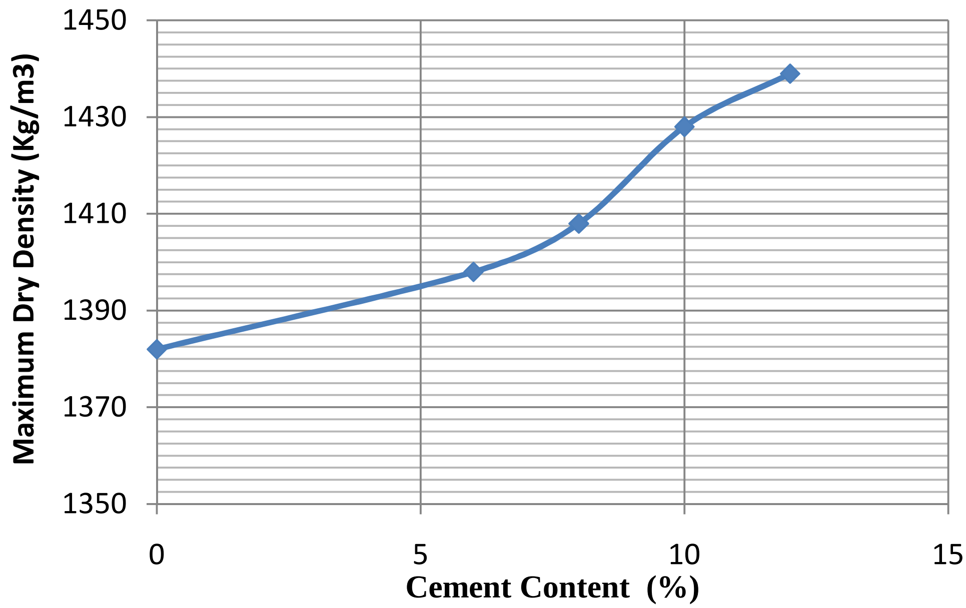

Figure 4-4 Effects of cement content on the Dry Density

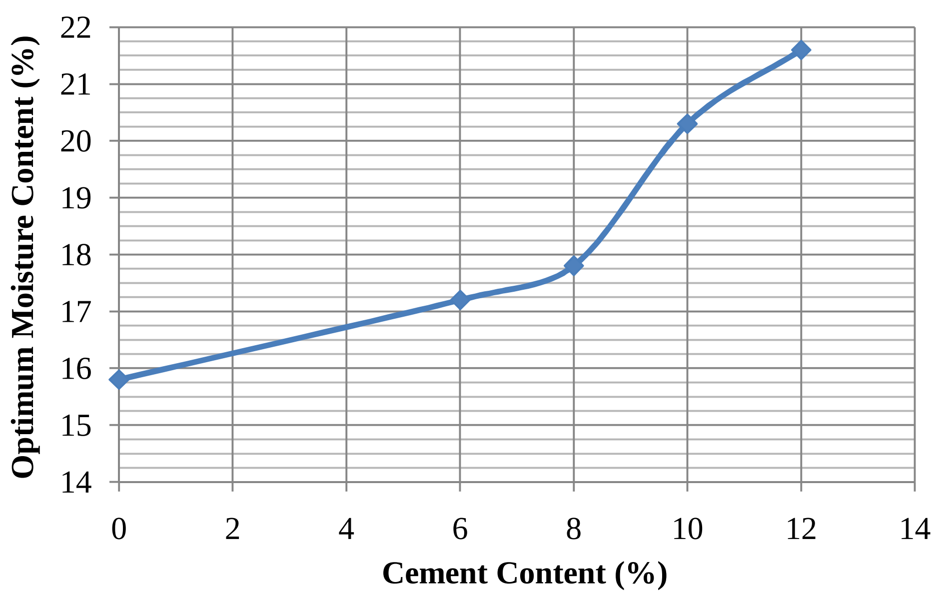

Figure 4-5 Effects of cement on the moisture content

From the compaction test, it can be seen that the MDD increased with the increase in cement content and the OMC decreased with increase in cement content. MDD increased from 1382kg/m^3 for the unstabilized/natural soil to 1439kg/m^3 for the stabilized soil with 12% cement content. The cement dosage was from 6% to 12% by weight of dry soil. According to Otoko, and Precious, (2014), the increase in MDD with cement content may be attributed to the relative higher specific gravity of cement to that of the soil of 2.55.

The OMC of the black cotton soil also increased with the increase of cement content. This might have been as a result of water needed for the hydration of cement as it reacts and binds the soil particles together. The OMC increased from 15.8% for unstabilized soil to 21.6% for the 12% cement content in the stabilized soil. This implies that upon obtaining this, the particles will be sufficiently lubricated and it will be possible to compact the soil to its minimum volume.

4.2 Mechanical properties of the soil sample

4.2.1 Unconfined compressive strength

Unconfined compressive strength (UCS) has always been considered the most common and adaptable method of evaluating the strength of stabilized soil. Variation of UCS with increase in cement content from 0% to 12% for 7 days cured specimens were tested and the results shown in appendix X and XI. The average UCS values were used to plot Figure 4-6. It can be deduced that there was a tremendous improvement in the UCS with addition of cement to the natural soil when compared with the low UCS value of 268KPa for the natural soil. This increasing trend was observed after 7 days of curing period where the UCS increased from 268KPa at 0% to 734KPa at 6%, 849KPa at 8%, 1087KPa at 10% and 1188KPa at 12% cement content. The increase in cement content in the stabilized soil results in deposition of interlocking cement gel between the soil particles binding the soil particles together and creates high strength. Therefore the increase in UCS is due to increase in cement content.

According to Oriola, & Saminu, (2012), the increase in UCS values could be attributed to ion exchange at the surface of clay particles. The chlorides in the cement additive reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration and flocculation of the clay particles. The increase in UCS after the 7 days curing was due to the long-term hydration reaction that resulted in the formation of newer compounds due to the presence of chlorides which are known to be stabilizing agents. This implies that the introduction of cement or a stabilizer in the sample soil leads to increased compressive strength.

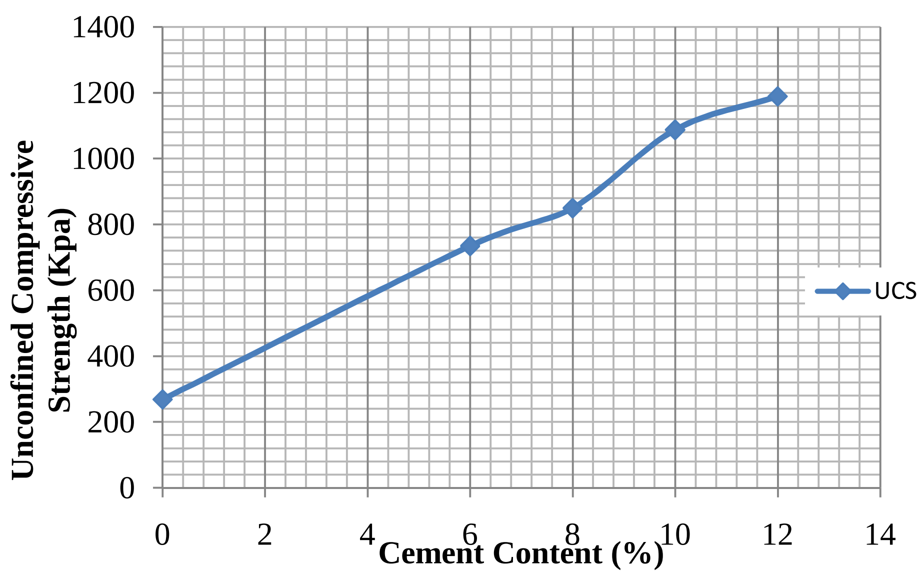

Figure 4-6 Effect of cement content on unconfined compressive strength

4.2.2 Compressive strength of cement stabilized blocks

Blocks were made with unstabilized soil and stabilized soil with varying cement contents percentage to dry weight of soil. The blocks were tested for the compressive strength at 7, 14 and 28 days and the results are as shown in appendices IX and the averages shown in Table 4-4.

Table 4-4 Interlocking blocks compressive strength test results

Interlocking blocks compressive strength test results			
	Average compressive strength (MPa)		
Soil mixes used	7 Days	14 Days	28 Days
Black cotton soil (BCS)	0.28	0.494	0.811
BCS + 6% cement	0.529	1.376	2.434
BCS + 8% cement	0.67	1.517	2.575
BCS + 10% cement	0.776	1.623	2.646
BCS + 12% cement	1.093	1.764	3.104

The results of the average compressive strengths in Table 4-4 are plotted in Figures 4-7 and 4-8 for cement stabilized blocks respectively. It can be observed from figure 4-7 that the compressive strength of cement stabilized interlocking blocks increased as the percentage of cement increased. The compressive strength of unstabilized interlocking blocks (the control) varied from 0.280 MPa to 0.811 MPa as the curing age increased from 7 to 28 days. For cement stabilized interlocking blocks it varied from 0.529 MPa to 2.434 MPa, 0.670 MPa to 2.575 MPa, 0.776 MPa to 2.646 MPa and 1.093 MPa to 3.104 MPa for 6%, 8%, 10% and 12% stabilization, respectively, during the same period of curing. In general, the compressive strength results are obtained by dividing the maximum force by the area of the specimen.

Figure 4-8 shows the strength development of interlocking blocks at various cement contents. From the Figure, it can be deduced that the mixture with 8%, 10% and 12% cement content achieved the allowable minimum standard compressive strength of 2.5MPa after 28 days. It is on the other hand important to appreciate that at reduced clay contents the strength results would have been higher.

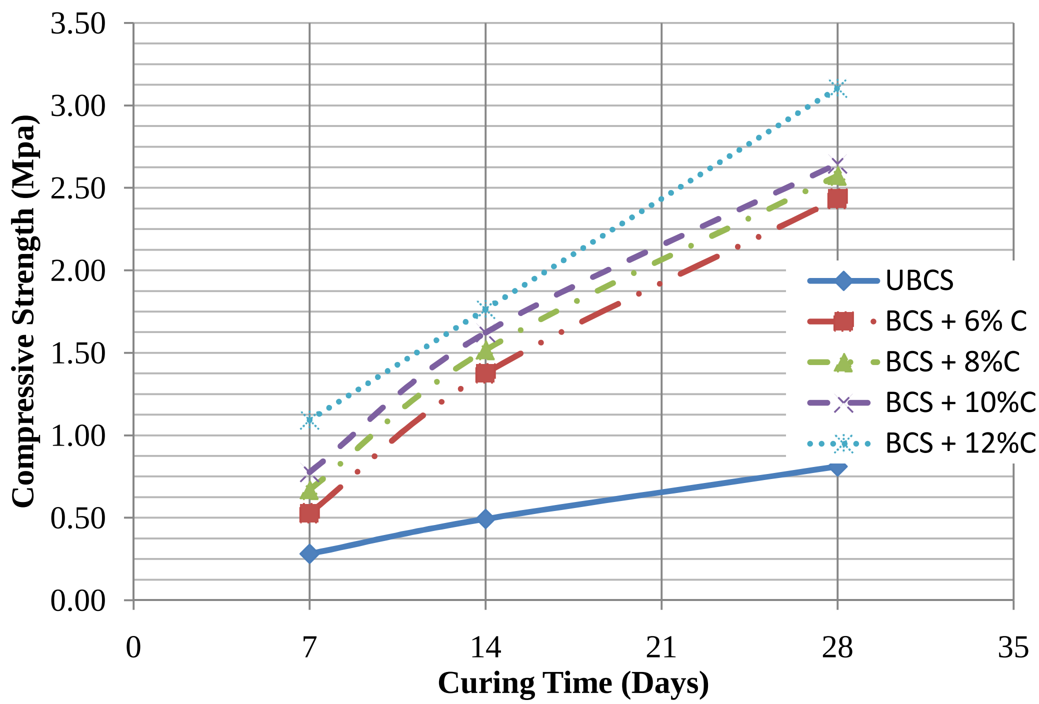

Figure 4-7 Compressive strength development for interlocking blocks

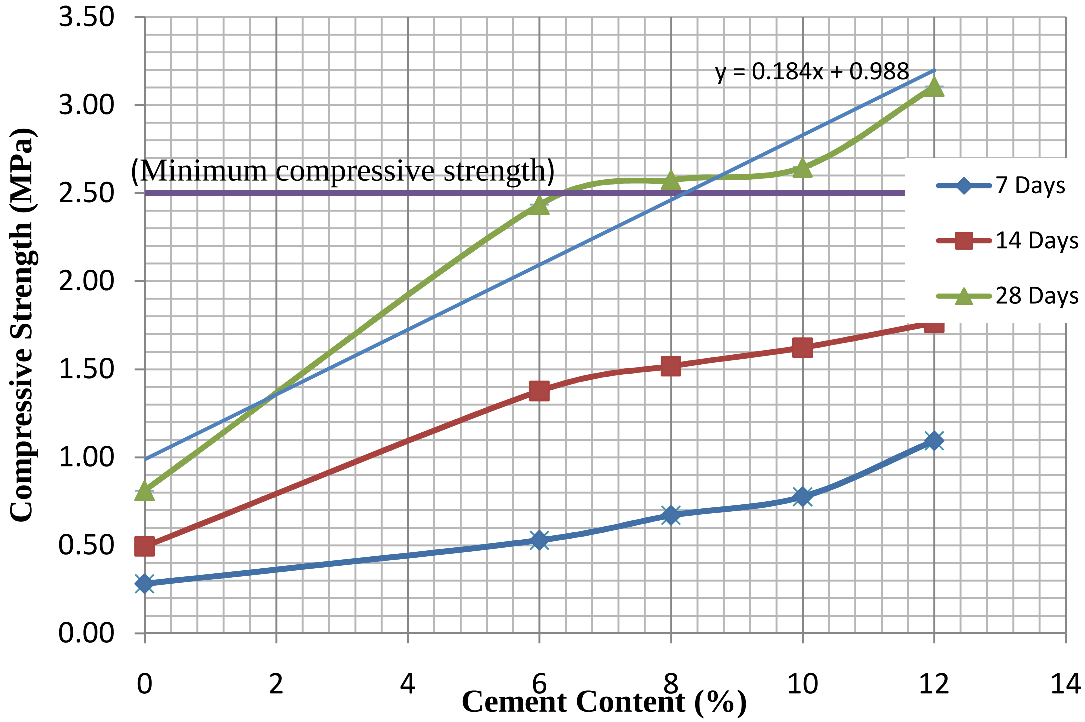

Figure 4-8 Effects of cement content on the compressive strength

The unstabilized blocks showed some strength but it didn't achieve the required standard strength. The blocks had some cracks developing immediately after demoulding and keeping them for curing. This might be due to the chemical nature of soil where the soil hardens and the bonds start weakening.

From the analysis, it was observed that 12%, 10% and 8% cement content in stabilizing the soil met the minimum required standard compressive strength of 2.5MPa as per the Kenyan Standard, KS 02-1070:1993. Using a trend line (line of best fit) for the 28 days compressive strength data, approximately 8% cement content was found to be the minimum required cement content which can stabilize black cotton soil and still obtain the minimum required compressive strength.

4.3 Introduction of rice husk ash into the mix proportion

4.3.1 Chemical composition of RHA

Elemental analysis in the RHA was carried out and the results were obtained by using X-ray fluorescence technique. The results are as shown in table 4-5.

Table 4-5: Chemical composition of rice husk ash

CONSTITUENT	**PERCENTAGE BY WEIGHT (%)**		
	RHA used	Kamau *et al**	Cement (OPC)**
SiO_2	82.34	85.00 ± 1.47	20.9
Fe_2O_3	1.02	0.23 ±0.06	3.41
Mn_2O	0.31	0.12 ±0.01	
MgO	0.91	0.43 ±0.12	1.25
CaO	1.02	0.67 ± 0.30	65.41
Na_2	0.10	0.07 ± 0.02	
Al_2O_3	1.06	0.32 ± 0.08	4.76
K_2O	2.67	1.24 ± 0.29	
P_2O_5	0.83	0.71 ± 0.42	
SO_2	-	-	2.71
Loss on ignition	15.4	6.93 ± 1.33	2
Total %		95.72 ± 1.25	

*Source: Kmau et al, 1993
**Source: Neville, 2009

XRF analysis confirmed that SiO_2, Fe_2O_3, CaO, Al_2O_3 and K_2O were found to be the major constituents of the ash. The total percentage composition of iron oxide (Fe_2O_3 = 1.02%), Silicon dioxide (SiO_2 = 82.34%) and Aluminum Oxide (Al_2O_3 = 1.06%) was found to be 84.42%. This value was less than the 85.5% obtained by Kamau, et al, (1993) but was within the required value of 70% minimum for pozollanas (ASTM C 618, 2003). According to Oyetola and Abdullahi, (2006), the slight difference in percentage composition might have resulted from the method of preparation of the ash and the species of the rice used.

Therefore, the RHA qualified to be used as a pozollana and could be classified as Class F pozollana, (ASTM C 618, 2003). The loss on ignition obtained was 15.4% which is higher than 10% maximum as required for pozzolanas. It meant that the RHA contained little unburnt carbon and this reduced the pozzolanic activity of the ash. The unburnt carbon is not pozzolanic and its presence in the mixture serves as filler material (Oyetola and Abdullahi, 2006).

4.3.2 Compaction of soil stabilized with cement and RHA

The compaction tests of the cement and RHA stabilized mixture was carried out after obtaining the minimum amount of cement and results are as indicated in the Appendix XII. These results were plotted in Figure 4-9 showing the relationship between the MDD and OMC.

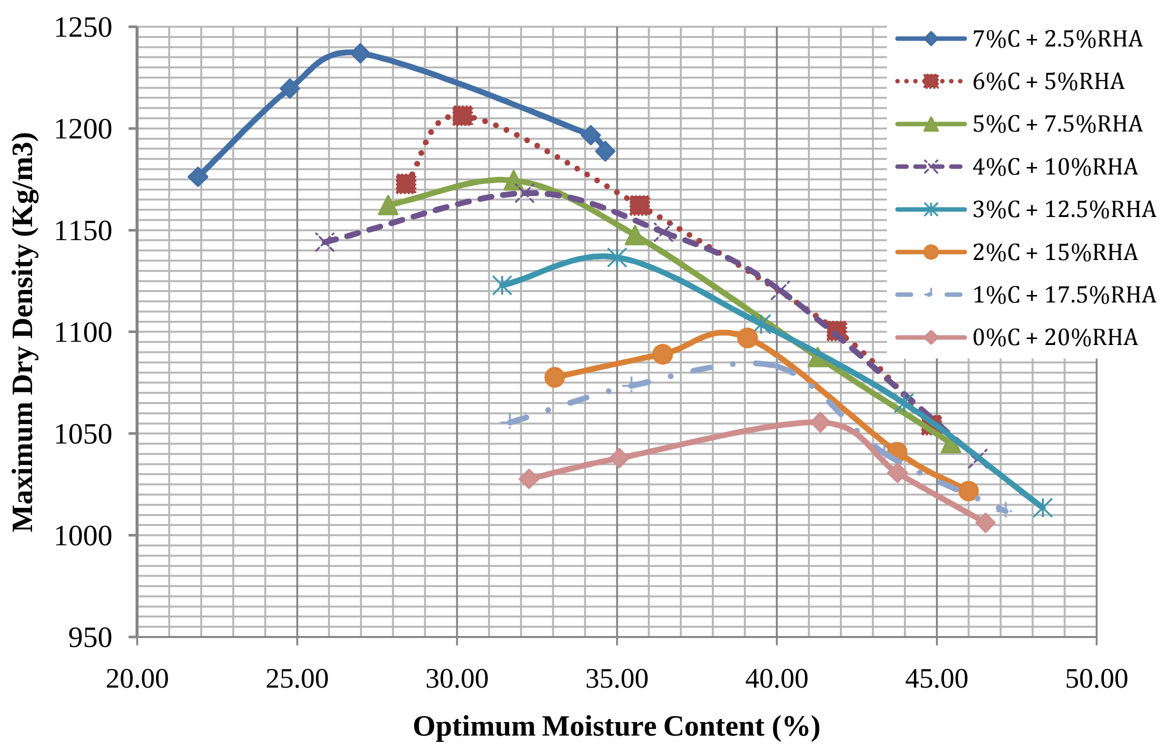

Figure 4-9 Variation of MDD with OMC for cement and RHA stabilized soil

From figure 4-9, the MDD and OMC of each stabilized mixture were determined and are as indicated in appendix XIII. These results were used to plot Figures 4-10 and 4-11 showing the effects of cement and RHA on the MDD and OMC respectively.

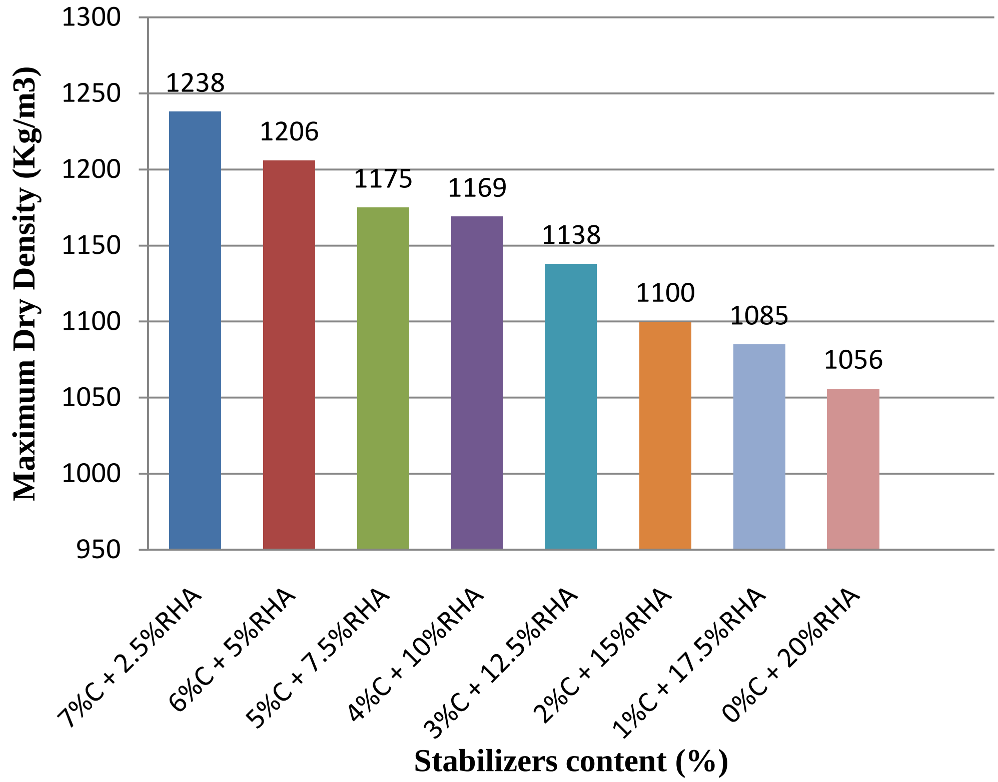

Figure 4-10 Effects of cement and RHA content on the MDD of soil

Figure 4-10 shows that at different cement contents, the results indicated a decrease in the MDD with increasing RHA contents, to the minimum at 0% cement and 20% RHA. The decrease in the MDD could be attributed to the replacement of soil and cement by the RHA, which had relatively lower specific gravity of average of 2.10 (Hisham *et al*, 2012), compared to that of soil and Portland cement of 2.55 and 3.15 respectively. It may also be attributed to coating of the soil cement by the RHA which resulted to large particles with larger voids and hence less density. According to Sarkar *et al* (2012), the MDD of soil decreases with an increase of RHA content due to comparatively low specific gravity value of RHA than that of replaced soil and the initial simultaneous flocculation; agglomeration of clay particles caused by cation exchange may be the another cause. Decreasing MDD indicates that the compaction energy is less than the natural state.

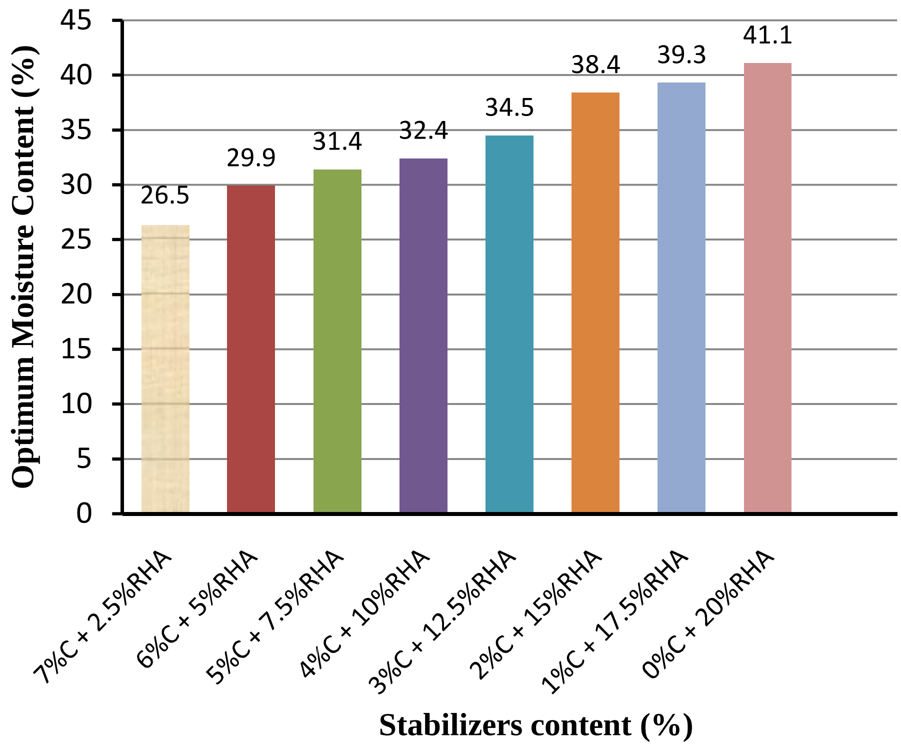

Figure 4-11 Effects of cement and RHA content on the OMC of soil

The OMC showed an increase with decrease in cement content and an increase of RHA. From 7% cement content to 0% cement content and 2.5% to 20% RHA content OMC relatively increased. This can be seen from Figure 4-11 where the OMC increased from 26.5% to 41.5% for the 7% C + 2.5% RHA to 0% C + 20% RHA respectively. The increase in OMC was due to the addition of RHA combined with cement in the soil mixture, which increased the finer materials with smaller surface area which combined together with the clay particles forming lumps with larger surface area which needed more water for the process to take place.

According to Alhassan & Mustapha, (2007) the nature of the process requires water for it to take place and water for hydration of cement is required; this leads to increase in water for compaction as RHA content increased. According to Sarkar *et al* (2012), the optimum moisture content of soil increased with an increase RHA because RHA are finer than the soil. The more fines the more surface area, so more water is required to provide well lubrication. The RHA content also decrease the quantity of free silt and clay fraction, forming coarser materials, which occupy larger spaces for retaining water. The increase of water content was also attributed by the pozzalanic reaction of RHA with the soil.

4.3.3 Compressive strength analysis for Cement and RHA stabilized blocks

The blocks were tested for the compressive strength at 7, 14 and 28 days. The raw data of the interlocking blocks compressive strength are presented in a tabulated form in Appendix XIV. The mean compressive strength results are summarized in Table 4-6 and presented in graphical form in Figures 4-12 and 4-13.

Table 4-6 Mean compressive strength for cement and RHA stabilized soil blocks

Mix	Mean compressive strength		
	7 Days	**14 Days**	**28 Days**
7%C + 2.5%RHA	1.327	1.834	2.787
6%C + 5%RHA	1.025	1.228	2.504
5%C + 7.5%RHA	0.894	1.038	2.363
4%C + 10%RHA	0.748	0.981	2.039
3%C + 12.5%RHA	0.504	0.596	1.825
2%C + 15%RHA	0.402	0.613	1.79
1%C + 17.5%RHA	0.375	0.594	1.312
0%C + 20%RHA	0.434	0.466	1.451

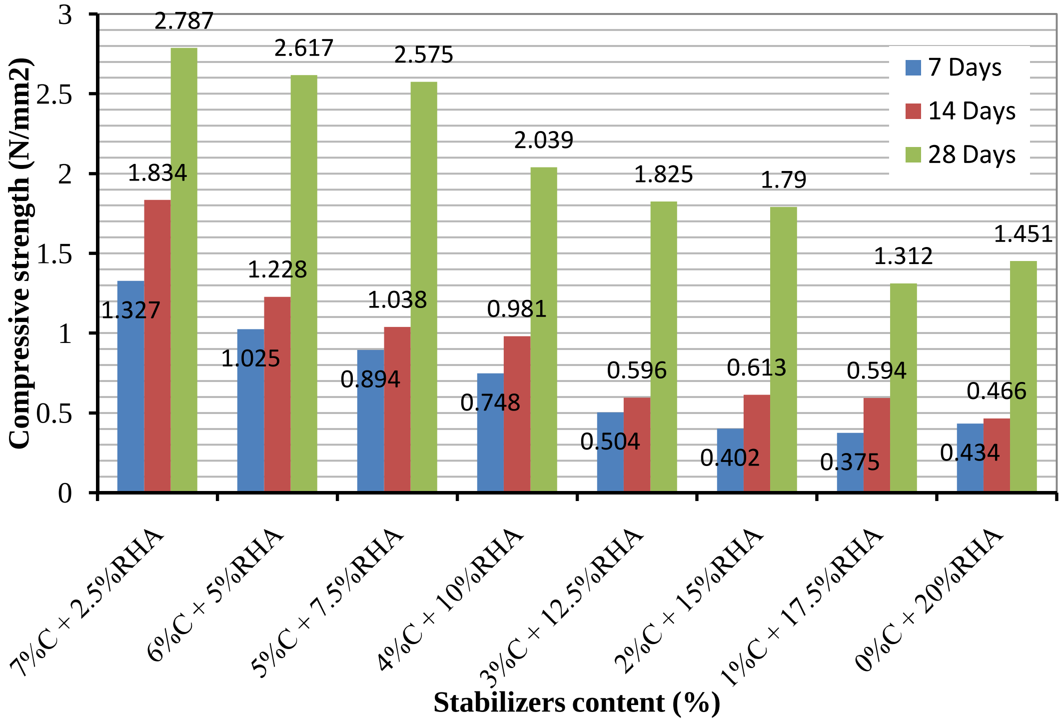

Figure 4-12: Effects of cement and RHA content on the compressive strength

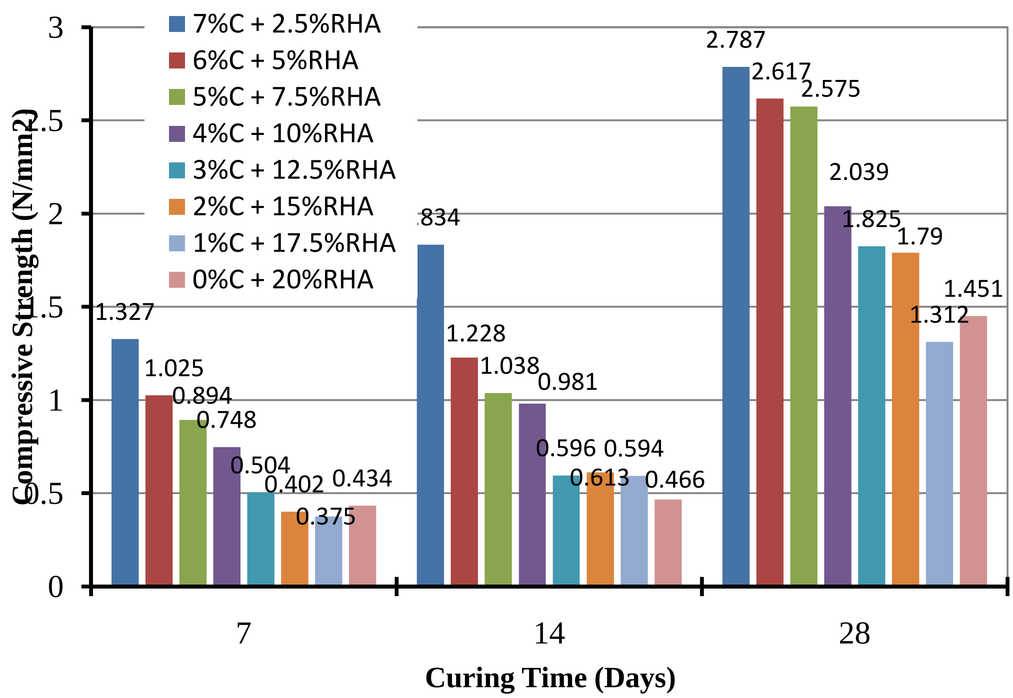

Figure 4-13 Strength development of cement and RHA stabilized blocks.

For a given constant decrease in cement content and increase in RHA content, a decrease in mean compressive strength of the blocks can be recognized. This can be due to decrease in cement content resulting in less deposition of cement gel between soil particles. The interlocking cement gel between the soil particles binds the soil particles together and creates high strength for 7% cement content and low strength for 0% cement content. After 7 days of curing and testing of blocks, the compressive strength for the blocks ranged from 1.327 MPa for 7% cement with 2.5% RHA to 0.224 MPa for 0% cement with 20% RHA. After 14 days of curing, there was no significant change in the compressive strength for all stabilizer contents in the soil. For 7% cement with 2.5% RHA, the strength was 1.834 MPa which showed an increment of 0.507 MPa and for 0% cement with 20% RHA the strength was 0.372 MPa showing an increment of 0.148 MPa. The 28 days compressive strength increased drastically for all the mixes. For 7% cement with 2.5% RHA, the compressive strength was 2.787 MPa and it decreased with decrease in cement content when partially replaced with RHA to 1.041 MPa for 0% cement with 20% RHA. This decrease in strength might be due to the amorphous nature of the RHA and the reduction in cement for hydration purposes which helps in binding.

Figure 4-13 shows that there was an increase in compressive strength of the stabilized blocks with curing time. This means that hydration of cement with the rice husk ash was slow in the early days and it needs time for the whole reaction to take place. The unstabilized soil blocks compressive strength for 7, 14 and 28 days were 0.28 MPa, 0.494 MPa and 0.811 MPa respectively. Comparing these with the 20% RHA stabilized soils blocks which are 0.224 MPa, 0.372 MPa and 1.041 MPa for 7, 14 and 28 days respectively, the 7 and 14 days compressive strength were higher for unstabilized soil blocks than the ones stabilized with RHA. According to Okunade (2008), early compressive strength for clay soils is due to the bonding of clay minerals. These will not be sustained for long and the strength increases with a slow rate due to weakening of the bonds. For the RHA stabilized blocks, hydration takes a long time thus low early strength and higher strength at 28 days.

According to the Kenyan Standard (KS 02-1070: 1993), the minimum required compressive strength is 2.5MPa and the minimum British Standard requirement is 2.8MPa for precast concrete masonry units and load bearing fired clay. Where building loads are small (e.g. in the case of single storey constructions), a compressive strength of 1 - 4MPa may be sufficient. Many building authorities around the world recommend values within this range. From the analyzed results, the

28 day compressive strength for blocks stabilized with 5% cement with 7.5% RHA, 6% cement with 5% RHA and 7% cement with 2.5% RHA achieved the minimum required standard strength of 2.5MPa. This implies that the blocks can be recommended for utilization in single storey constructions and interior non-load bearing walls for other construction purposes.

4.3.4 Wet compressive strength and water absorption tests

The blocks were partially submerged in water for a period of 24 hours and all the blocks tended to have absorbed water and reduced in strength significantly. From the results shown in Table 4-7, it was be observed that the time to the start of breaking down and rupture time of blocks seemed to vary in direct relation partial replacement of cement with RHA. The blocks stabilized with 8% cement had a longer time to start of breaking down of 6hrs 20 minutes and the blocks with 0% cement + 20% RHA broken in 30 minutes.

Table 4-7: Water absorption test results

Mix Proportion	**Average time to start breaking down**	**Average time to block rupture**
8%C + 0%RHA	6hrs 20min	12 hrs
7%C + 2.5%RHA	5hrs	8hrs
6%C + 5%RHA	3hrs 50min	6hrs 25min
5%C + 7.5%RHA	3hrs 20min	5hrs 50min
4%C + 10%RHA	2hrs	5hrs 40min
3%C + 12.5%RHA	1hr 20min	5hrs 30min
2%C + 15%RHA	50min	3hrs 20min
1%C + 17.5%RHA	25min	3hrs
0%C + 20%RHA	10min	2hrs

The rupture time was great with an average of 12hrs for the blocks stabilized with 8% cement and 2hrs for 20 % RHA. Water absorption of the blocks increased with the increase in RHA and decrease in cement content in the mixture. This is due to the fact that the breakdown time was high for blocks with 8% cement and decreased gradually as the cement reduced and RHA increased in the blocks. The breakdown of the blocks began on the surface, where the block was driest and hence most prone to absorb water through the pores.

It was not possible to lift the compressed stabilized earth blocks out of the water without them crumbling. Thus the blocks were considered to be weak in wet compressive strength and water absorption thus could not be utilized in moist environment. The failure of the blocks in wet compressive and water absorption tests meant that a water proofing material must be used for the blocks to be utilized in external walls or areas exposed to wet environment.

4.3.5 Linear shrinkage of the interlocking blocks

The objective of this test was to determine what effect the various stabilizers have on the drying shrinkage of the block over a period of twenty-eight days.The blocks were measured using a vernier calliper after being sun dried and to get the dimensional changes of the blocks from wet to dry condition. The results are as shown in table 4-8 and analysed in figure 4-14. The blocks stabilized with 7% cement and 2.5% RHA did not shrink at all as it maintained its original length. The blocks with 6% cement and 5% RHA, and those with 5% cement and 7.5% RHA had the same shrinkage of 0.87% showing that the introduction of RHA had an effect on the shrinkage of the blocks. Blocks made of 1% cement with 17.5% RHA had the highest shrinkage of 4.35% and those with RHA alone of 20% content had shrinkage of 3.04%.

Table 4-8: Linear shrinkage test results

Mix	Original L (mm)	Shrinked L (mm)	Change in L (%)
7%C + 2.5%RHA	230	230	0
6%C + 5%RHA	230	228	0.87
5%C + 7.5%RHA	230	228	0.87
4%C + 10%RHA	230	227	1.30
3%C + 12.5%RHA	230	227	1.30
2%C + 15%RHA	230	224	2.61
1%C + 17.5%RHA	230	220	4.35
0%C + 20%RHA	230	223	3.04

As the cement content decreases and the RHA increases, the linear shrinkage of the blocks increased. This shows that the introduction of RHA increased the shrinkage of the blocks as seen in Figure 4-14. This could possibly affect the interlocking mechanism between overlaying and underlying blocks. If for instance the overlaying blocks have a high drying shrinkage, they will not interlock with underlying blocks with a low drying shrinkage, with the extreme possibility of causing dimensional instability.

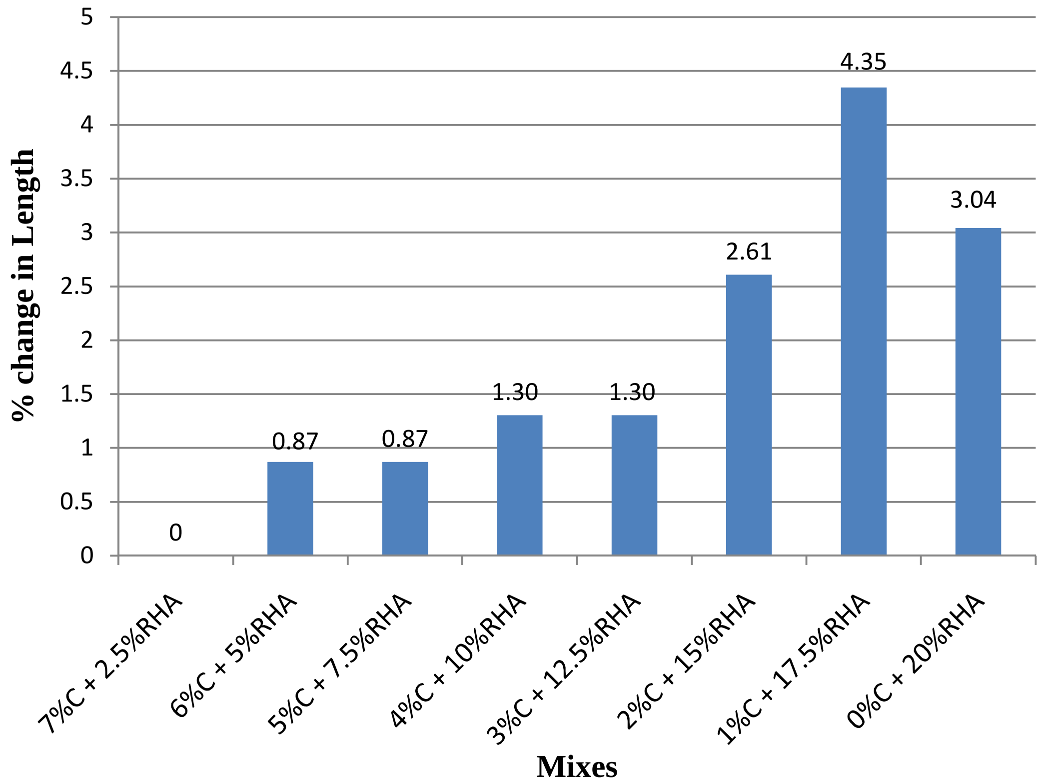

Figure 4-14 Linear shrinkage of interlocking blocks

It was observed that surface cracking occurred in the blocks and the amount of cracking decreased with increase in cement content. Increase in RHA content also showed visible reduction in surface cracking of the blocks. Therefore, RHA helps reduce or minimizes the development of cracks in compressed stabilized clay earth blocks.

4.4 Cost analysis

Utilizing 5% cement with 7.5% rice husk ash which had a compressive strength of 2.575 MPa which met the minimum required compressive strength of 2.5MPa recommended for internal walling purposes. The cost of using this mix proportion was compared with the cost of the block made using the minimum percentage of cement required which is 8%, for production of interlocking stabilized blocks. Assume the average cost of 50kg bag of cement is Kenya Shillings (KES) 700 and one unskilled labour producing 150 blocks in a day is paid Kenya Shillings (KES) 450 for that day's job. Labour cost will be constant for both cases.

Table 4-9: Costs incurred in production of stabilized clay earth blocks

Description	8% cement	5% cement + 7.5% RHA
Cost of 50kg of cement	700	700
Cost of acquiring 50kg of RHA	_	200
Transport of 50kg of RHA from Mwea	_	300
Transport of 50kg of cement from Thika	200	200
Transport of 1 tonne of soil from Juja	400	400
Daily labour cost for producing blocks	450	450
Total expenditure (Kenya shillings)	1750	2250

Table 4-10: Cost analysis of produced stabilized clay earth blocks

Description	8% cement	5% cement + 7.5% RHA
No. of blocks produced with 50kg of cement	63	110
Cost of one block produced (KES)	28	20.50
Wall size build by the no. of blocks produced	1.85	3.23

For each block produced with cement and rice husk ash, 3% of cement is saved. 100kg of soil with 5% cement and 7.5% rice husk ash produced 11 blocks. Therefore a bag of cement with rice husk ash produced approximately 110 blocks. Utilizing cement alone in block production meant 100kg of soil with 8% cement produce 10 blocks and thus a bag produced approximately 63 blocks. The cost of cement used in producing one cement stabilized block was approximately KES 28 while for cement and RHA stabilized block was approximately KES 20.50.

Square meter wall required approximately 34 interlocking blocks. The 8% cement scenario could build approximately $1.85m^2$ of a wall while the 5% cement with 7.5% rice husk ash case could build approximately $3.23m^2$ of a wall. The cement stabilized earth blocks walling cost more compared to the walling made of blocks stabilized with cement and rice husk ash. This showed that the cost of an interlocking wall made of blocks stabilized with cement and rice husk ash could lead to the production of low cost housing by utilizing the two waste products (rice husks and clay).

5 CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. There are different types of black cotton soils. The black cotton soil sample used consisted of 13% gravel, 8% sand and 79% fines, classified as A-7-5 according to AASHTO system of classification, and requires a commensurate amount of stabilizer before it could be used for earth block production.

2. The minimum amount of cement required to achieve the minimum required compressive strength of 2.5 MPa after 28 day curing was 8% by weight of dry soil sample. When RHA was used as a partial replacement of cement, the optimum combination of cement and RHA was 5% and 7.5%, respectively.

3. Blocks stabilized with a minimum of 8% cement were more resistant to wetness. It took 6 hours and 12 hours to start disintegrating and finally rupturing respectively. The blocks with 5% cement + 7.5% RHA took about 50% of the time taken by 8% cement stabilized blocks to start disintegrating and finally rupturing.

4. This study showed that the construction cost of producing a single block upon utilizing 5% cement and 7.5 % RHA was 73% of the cost of producing a block using 8% cement alone as a stabilizer. Blocks stabilized with cement and RHA can build 1.75 times size of the wall built with cement stabilized blocks.

5. For the soil studied, 5% cement with 7.5% RHA could be utilized in production of compressed earth blocks which could be used in single storey constructions and interior non-load bearing walls for other construction purposes.

5.2 Recommendation

1. To avert the housing shortage in the country, the compressed stabilized earth blocks produced with the optimal mix of 5% cement and 7.5 % RHA should be used for partitioning and other unexposed works.
2. If the blocks are to be utilized in exposed environments, the walls should be plastered or painted with oil/water resistant paints.
3. Further research should be undertaken to establish the possibility of utilizing other additives such as bitumen, gypsum and lime with rice husk ash to stabilize black cotton soil to check on the possibility of improving the water absorption characteristics of the compressed earth blocks.

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APPENDICES

Appendix I: Particle size distribution - Wet sieving

Particle size distribution - Wet sieving			
Location: JKUAT-PAU		Date: 03/04/2014	
Tested by: RONOH VICTOR		Initial weight = 500g	
Sieve sizes (mm)	**Soil retained (g)**	**Percent retained (%)**	**Percent passed (%)**
19.1	0	0.00	100.00
9.52	33	6.61	93.39
4.76	18.2	3.64	89.75
2	27.9	5.58	84.17
0.84	20.6	4.12	80.04
0.42	14.8	2.96	77.08
0.25	12.2	2.44	74.64
0.105	17.6	3.52	71.12
0.074	5.2	1.04	70.08
Pan	350.1	70.08	0.00
	499.6		

Appendix II: Particle density/specific gravity

Particle density - small pycometer method				
Dry density/moisture content relationship				
Location: JKUAT-PAU		Date: 12/05/2014		
Tested by: RONOH VICTOR		Sample No.		
Pycometer No.	g	20	31	38
Mass of bottle + soil + water (M3)	g	174.78	170.62	166.07
Mass of bottle + soil (M2)	g	89.07	82.81	77.47
Mass of bottle full water (M4)	g	152	152.7	147.75
Mass of density bottle (M1)	g	51.57	53.36	47.33
Mass of soil (M2-M1)	g	37.5	29.45	30.14
Mass of water in full bottle (M4-M1)	g	100.43	99.34	100.42
Mass of water used (M3-M2)	g	85.71	87.81	88.6
Volume of soil particles	ml	14.72	11.53	11.82
Particle Density	kg/m^3	2547.554	2554.206	2549.915
Average particle density (kg/m^3)			2550.56	

Appendix III: Atterberg Limits of a soil

DETERMINATION OF ATTERBERG LIMITS OF A SOIL								
Location		JKUAT-PAU				Date: 27/03/2014		
Tested by		RONOH VICTOR				Sample No.		
Test details:	Proportions of sample on 425 Micron BS test sieve							
Soil condition:		Air dried						
Test No.		1	2	3	4	5	6	7
Cone Penetration	(mm)	15.1	18.5	20.4	21.1	24.2	PL	PL
Tin No.		3	4	5	2	11A	36	12A
Wt.of wet soil+Tin	(g)	29.68	33.8	38.84	46.33	29.7	31.68	16.59
Wt.of dry soil+Tin	(g)	20.54	22.57	24.98	28.39	17.68	28.22	13.59
Wt.of tin	(g)	9.28	9.51	9.53	9.34	5.53	16.2	5.28
Wt.of moisture	(g)	9.14	11.23	13.86	17.94	12.02	3.46	3
Wt.of dry soil	(g)	11.26	13.06	15.45	19.05	12.15	12.02	8.31
Moisture content	(%)	81.17	85.99	89.71	94.17	98.93	28.79	36.10
						Av. PL		32.44
Atterberg Limit Tests			Linear Shrinkage					
Liquid Limit	90.25	%	Trough No.					
Plastic Limit	32.44322	%	Initial length of specimen (A)				140	mm
Plasticity Index	57.80678	%	Length of oven dry specimen (B)				117.4	mm
Linear Shrinkage	16.14286	%	Linear shrinkage % (100(1-B/A))				16.14286	%

Appendix IV: Compaction Test Soil with 0% Cement

Compaction test soil with 0% cement								
Dry density/moisture content relationship - 0% cement								
Location	JKUAT-PAU				Date: 26/03/2014			
Tested by	RONOH VICTOR				Sample No.			
Compaction type					Layer			
Water to add	ml	200	300	400	500	600	700	800
Wt. of Wet soil+Mould	(g)	5543.8	5631.4	5789.2	5808	5806.2	5773.1	5732.5
Wt. of mould	(g)	4168.8	4168.8	4168.8	4168.8	4168.8	4168.8	4168.8
Wt. of wet soil	(g)	1375	1462.6	1620.4	1639.2	1637.4	1604.3	1563.7
Volume of mould	(cm^3)	1000	1000	1000	1000	1000	1000	1000
Bulk density of soil	(g/cm^3)	1.375	1.463	1.620	1.639	1.637	1.604	1.564
Dry density of soil	kg/m3	1246	1303	1382	1372	1348	1291	1246
Tin No.		38	35	37	20	24	5A	6A
Wt. of wet soil+Tin	(g)	76.1	82.7	99.8	84.3	93.1	55.5	72.4
Wt. of dry soil+Tin	(g)	71.1	75.5	87.5	72.1	78.3	45.7	58.8
Wt. of tin	(g)	22.9	16.7	16.5	9.4	9.4	5.5	5.5
Wt. of moisture	(g)	5.0	7.2	12.3	12.2	14.8	9.8	13.6
Wt. of dry soil	(g)	48.2	58.9	71.0	62.7	68.9	40.2	53.3
Moisture content	(%)	10.4	12.2	17.3	19.5	21.5	24.3	25.5

Appendix V: Compaction Test Soil with 6% Cement

Compaction test soil with 6% cement							
Dry density/moisture content relationship							
Location	JKUAT-PAU				Date: 04/04/2014		
Tested by	RONOH VICTOR				Sample No.		
Compaction type			Layer				
Water to add	ml	400	500	600	700	800	900
Wt. of wet soil+Mould	(g)	5649.3	5745.2	5811.6	5811.1	5787	5711.3
Wt. of mould	(g)	4167.5	4167.5	4167.5	4167.5	4167.5	4167.5
Wt. of wet soil	(g)	1481.8	1577.7	1644.1	1643.6	1619.5	1543.8
Volume of mould	(cm^3)	1000	1000	1000	1000	1000	1000
Bulk density of soil	(g/cm^3)	1.482	1.578	1.644	1.644	1.620	1.544
Dry density of soil	kg/m3	1321	1376	1394	1367	1287	1215
Tin No.		1	3	5	8	10	11
Wt. of wet soil+Tin	(g)	53.1	37.3	40.5	38.8	48.0	39.7
Wt. of dry soil+Tin	(g)	48.0	33.4	35.3	33.3	39.5	32.6
Wt. of tin	(g)	6.3	6.4	6.4	6.4	6.4	6.4
Wt. of moisture	(g)	5.1	4.0	5.2	5.5	8.6	7.1
Wt. of dry soil	(g)	41.7	27.0	28.9	26.9	33.1	26.2
Moisture content	(%)	12.2	14.7	17.9	20.3	25.9	27.1

Appendix VI: Compaction test soil with 8% cement

Compaction test soil with 8% cement						
Dry density/moisture content relationship						
Location	JKUAT-PAU				Date: 04/04/2014	
Tested by	RONOH VICTOR				Sample No.	
Compaction type			Layer			
Water to add	ml	400	500	600	700	800
Wt. of wet soil+Mould	(g)	5726.7	5785.6	5829.2	5812.9	5751.5
Wt. of mould	(g)	4167.5	4167.5	4167.5	4167.5	4167.5
Wt. of wet soil	(g)	1559.2	1618.1	1661.7	1645.4	1584
Volume of mould	(cm^3)	1000	1000	1000	1000	1000
Bulk density of soil	(g/cm^3)	1.559	1.618	1.662	1.645	1.584
Dry density of soil	kg/m3	1352	1389	1410	1328	1234
Tin No.		14	5	28	2	4A
Wt. of wet soil+Tin	(g)	48.7	49	35.5	41.8	52.7
Wt. of dry soil+Tin	(g)	43.5	43.4	31.6	35.5	43.2
Wt. of tin	(g)	9.4	9.5	9.4	9.3	9.5
Wt. of moisture	(g)	5.2	5.6	4.0	6.3	9.6
Wt. of dry soil	(g)	34.1	33.9	22.2	26.2	33.7
Moisture content	(%)	15.4	16.5	17.8	23.9	28.4

Appendix VII: Compaction test soil with 10% cement

Compaction test soil with 10% cement						
Dry density/moisture content relationship						
Location	JKUAT-PAU				Date: 04/04/2014	
Tested by	RONOH VICTOR				Sample No.	
Compaction type			Layer			
Water to add	ml	500	600	700	800	900
Wt. of Wet soil+Mould	(g)	5770.6	5807.3	5887	5873	5872.4
Wt. of mould	(g)	4167.5	4167.5	4167.5	4167.5	4167.5
Wt. of wet soil	(g)	1603.1	1639.8	1719.5	1705.5	1704.9
Volume of mould	(cm^3)	1000	1000	1000	1000	1000
Bulk density of soil	(g/cm^3)	1.603	1.640	1.720	1.706	1.705
Dry density of soil	kg/m3	1356	1380	1428	1384	1350
Tin No.		3	10	11	13	18
Wt. of wet soil+Tin	(g)	51.92	48.86	42.98	50.4	45.2
Wt. of dry soil+Tin	(g)	45.36	42.64	37.30	42.69	37.74
Wt. of tin	(g)	9.28	9.54	9.50	9.33	9.37
Wt. of moisture	(g)	6.6	6.2	5.7	7.8	7.5
Wt. of dry soil	(g)	36.1	33.1	27.8	33.4	28.4
Moisture content	(%)	18.2	18.8	20.4	23.2	26.3

Appendix VIII: Compaction test soil with 12% cement

Compaction test soil with 12% cement						
Dry density/moisture content relationship						
Location	JKUAT-PAU				Date: 04/04/2014	
Tested by	RONOH VICTOR				Sample No.	
Compaction type			Layer			
Water to add	ml	500	600	700	800	900
Wt. of wet soil+Mould	(g)	5772.4	5862.2	5899.1	5879.6	5870
Wt. of mould	(g)	4167.9	4167.9	4167.9	4167.9	4167.9
Wt. of wet soil	(g)	1604.5	1694.3	1731.2	1711.7	1702.1
Volume of mould	(cm^3)	1000	1000	1000	1000	1000
Bulk density of soil	(g/cm^3)	1.605	1.694	1.731	1.712	1.702
Dry density of soil	kg/m3	1363	1418	1431	1381	1348
Tin No.		5A	6A	7A	8A	9A
Wt. of wet soil + tin	(g)	53.81	41.25	47.9	53.9	54.8
Wt. of Dry soil + tin	(g)	47.2	36.1	41.2	45.3	45.4
Wt. of tin	(g)	9.56	9.48	9.32	9.4	9.4
Wt. of moisture	(g)	6.7	5.2	6.7	8.6	9.5
Wt. of dry soil	(g)	37.6	26.6	31.9	35.9	35.9
Moisture content	(%)	17.7	19.5	21.0	23.9	26.3

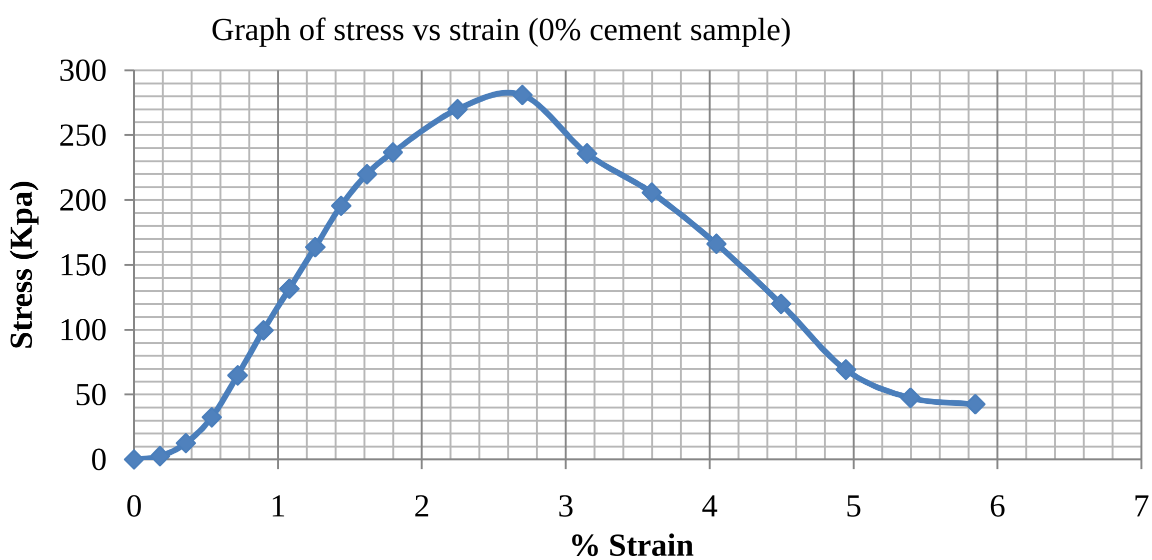
Appendix IX: Interlocking blocks compressive strength

Blocks compressive strength test results using black cotton soil and 0% cement								
S. No.	Age in days	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (kN)	Unit weight Kg/m^3	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	8950	15	1383.57	0.32	0.282
2	7	47250	6,468,750	9090	10	1405.22	0.21	
3	7	47250	6,468,750	9182	15	1419.44	0.32	
1	14	47250	6,468,750	8870.5	20	1371.29	0.42	0.494
2	14	47250	6,468,750	9011	25	1393.00	0.53	
3	14	47250	6,468,750	8698.5	25	1344.70	0.53	
1	28	47250	6,468,750	8515	30	1316.33	0.63	0.811
2	28	47250	6,468,750	9034	45	1396.56	0.95	
3	28	47250	6,468,750	9123	40	1410.32	0.85	
Blocks compressive strength test results using black cotton soil and 6% cement								
Sample	Age in days	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (kN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	9877	20	1526.88	0.423	0.529
2	7	47250	6,468,750	10802.5	25	1669.95	0.529	
3	7	47250	6,468,750	10739.5	30	1660.21	0.635	
1	14	47250	6,468,750	11070	70	1711.30	1.481	1.376
2	14	47250	6,468,750	10733.5	65	1659.29	1.376	
3	14	47250	6,468,750	10852	60	1677.60	1.270	
1	28	47250	6,468,750	9879	115	1527.19	2.434	2.434
2	28	47250	6,468,750	9910.5	110	1532.06	2.328	
3	28	47250	6,468,750	10772.5	120	1665.31	2.540	
Blocks compressive strength test results using black cotton soil and 8% cement								
Sample	Age in days	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10179.5	25	1573.64	0.529	0.670
2	7	47250	6,468,750	10494.5	35	1622.34	0.741	
3	7	47250	6,468,750	11161	35	1725.37	0.741	
1	14	47250	6,468,750	10967	70	1695.38	1.481	1.517
2	14	47250	6,468,750	11245	80	1738.36	1.693	
3	14	47250	6,468,750	10132.5	65	1566.38	1.376	
1	28	47250	6,468,750	9830	95	1519.61	2.011	2.575
2	28	47250	6,468,750	10730.5	105	1658.82	2.222	
3	28	47250	6,468,750	10315	165	1594.59	3.492	

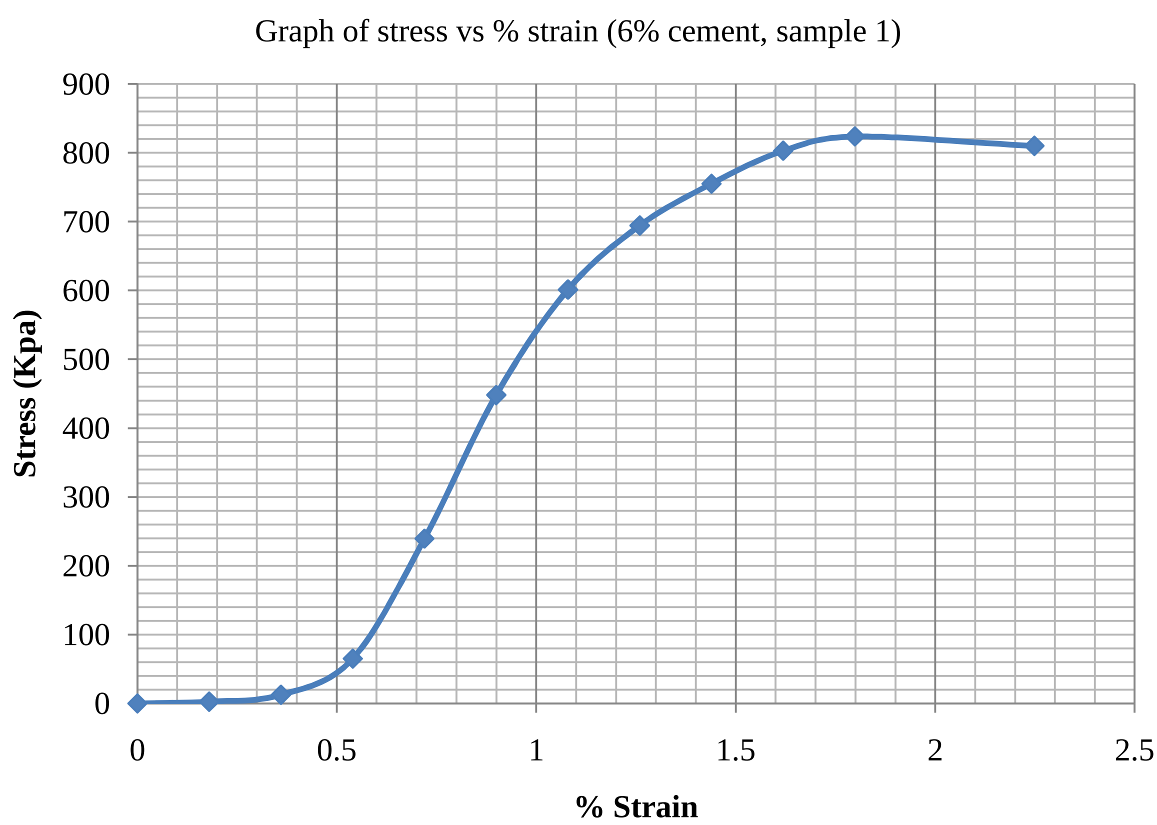
Blocks compressive strength test results using black cotton soil and 10% cement								
Sample	Age in days	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10399.5	40	1607.65	0.847	0.776
2	7	47250	6,468,750	10915.5	35	1687.42	0.741	
3	7	47250	6,468,750	10399	35	1607.57	0.741	
1	14	47250	6,468,750	10121.5	70	1564.68	1.481	1.623
2	14	47250	6,468,750	10514.5	80	1625.43	1.693	
3	14	47250	6,468,750	10540.5	80	1629.45	1.693	
1	28	47250	6,468,750	10389	140	1606.03	2.963	2.646
2	28	47250	6,468,750	10031	110	1550.69	2.328	
3	28	47250	6,468,750	10166	125	1571.56	2.646	
Blocks compressive strength test results using black cotton soil and 12% cement								
Sample	Age in days	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	11099	45	1715.79	0.952	1.093
2	7	47250	6,468,750	11323	50	1750.42	1.058	
3	7	47250	6,468,750	11669.5	60	1803.98	1.270	
1	14	47250	6,468,750	11056.5	85	1709.22	1.799	1.764
2	14	47250	6,468,750	11321.5	95	1750.18	2.011	
3	14	47250	6,468,750	10963.5	70	1694.84	1.481	
1	28	47250	6,468,750	10626	150	1642.67	3.175	3.104
2	28	47250	6,468,750	10606	125	1639.57	2.646	
3	28	47250	6,468,750	11074	165	1711.92	3.492	

Appendix X**:** Raw data of unconfined compression test

Results for 0% cement treated UCS samples							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.01	0.2	0.002	0.180	0.002099	0.005	2.506224
40	0.05	0.4	0.004	0.360	0.002103	0.026	12.50854
60	0.13	0.6	0.005	0.540	0.002106	0.068	32.46351
80	0.26	0.8	0.007	0.719	0.00211	0.137	64.8096
100	0.4	1	0.009	0.899	0.002114	0.210	99.52645
120	0.53	1.2	0.011	1.079	0.002118	0.279	131.6332
140	0.66	1.4	0.013	1.259	0.002122	0.347	163.6226
160	0.79	1.6	0.014	1.439	0.002126	0.416	195.4945
180	0.89	1.8	0.016	1.619	0.002129	0.468	219.8388
200	0.96	2	0.018	1.799	0.002133	0.505	236.6959
250	1.1	2.5	0.022	2.248	0.002143	0.579	269.9723
300	1.15	3	0.027	2.698	0.002153	0.605	280.9455
350	0.97	3.5	0.031	3.147	0.002163	0.510	235.8763
400	0.85	4	0.036	3.597	0.002173	0.447	205.7362
450	0.69	4.5	0.040	4.047	0.002183	0.363	166.2304
500	0.5	5	0.045	4.496	0.002194	0.263	119.8923
550	0.29	5.5	0.049	4.946	0.002204	0.153	69.21017
600	0.2	6	0.054	5.396	0.002214	0.105	47.50537
650	0.18	6.5	0.058	5.845	0.002225	0.095	42.55162

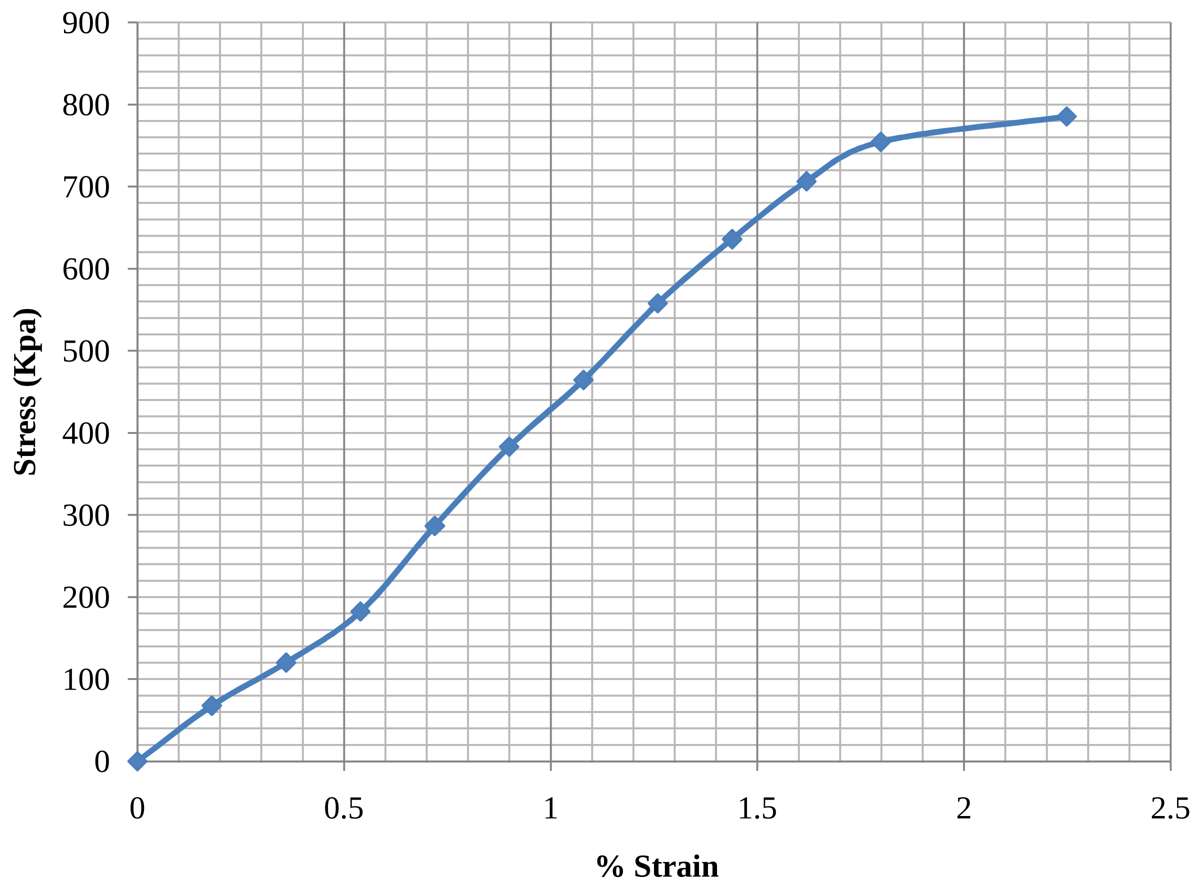


Results for 6% cement treated UCS samples (sample 1)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.01	0.2	0.002	0.180	0.002099	0.005	2.506224
40	0.05	0.4	0.004	0.360	0.002103	0.026	12.50854
60	0.26	0.6	0.005	0.540	0.002106	0.137	64.92701
80	0.96	0.8	0.007	0.719	0.00211	0.505	239.297
100	1.8	1	0.009	0.899	0.002114	0.947	447.869
120	2.42	1.2	0.011	1.079	0.002118	1.273	601.0422
140	2.8	1.4	0.013	1.259	0.002122	1.473	694.1564
160	3.05	1.6	0.014	1.439	0.002126	1.604	754.7573
180	3.25	1.8	0.016	1.619	0.002129	1.710	802.782
200	3.34	2	0.018	1.799	0.002133	1.757	823.5046
250	3.3	2.5	0.022	2.248	0.002143	1.736	809.9168

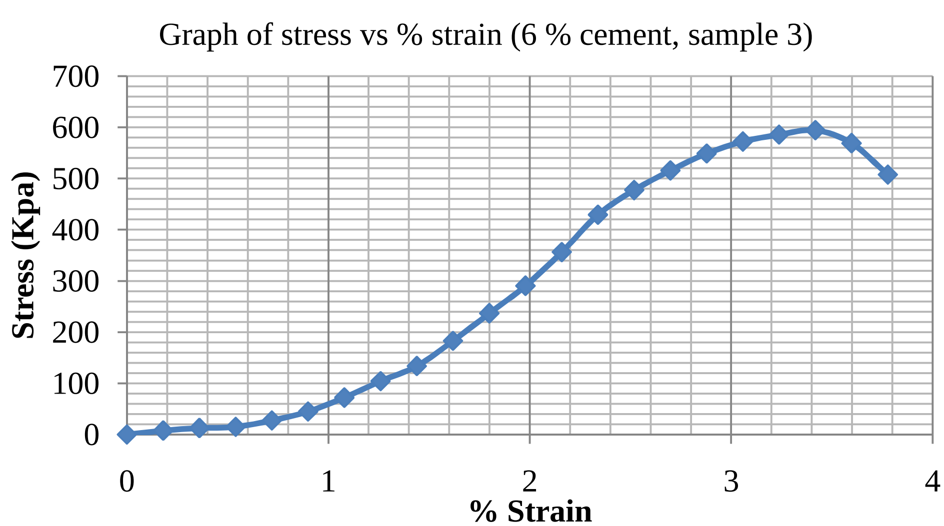


Results for 6% cement treated UCS samples (sample 2)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.27	0.2	0.002	0.180	0.002099	0.142	67.66805
40	0.48	0.4	0.004	0.360	0.002103	0.252	120.082
60	0.73	0.6	0.005	0.540	0.002106	0.384	182.2951
80	1.15	0.8	0.007	0.719	0.00211	0.605	286.6579
100	1.54	1	0.009	0.899	0.002114	0.810	383.1768
120	1.87	1.2	0.011	1.079	0.002118	0.984	464.4417
140	2.25	1.4	0.013	1.259	0.002122	1.184	557.8042
160	2.57	1.6	0.014	1.439	0.002126	1.352	635.9758
180	2.86	1.8	0.016	1.619	0.002129	1.504	706.4481
200	3.06	2	0.018	1.799	0.002133	1.610	754.4683
250	3.2	2.5	0.022	2.248	0.002143	1.683	785.3739

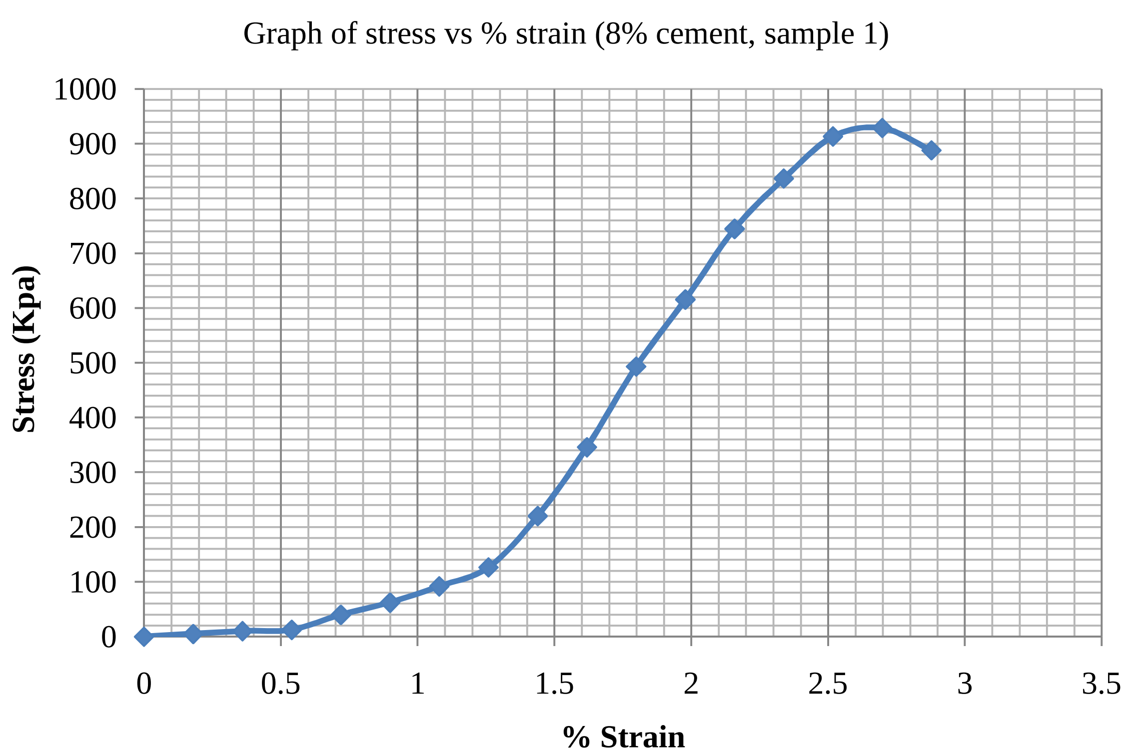
Graph of stress vs % strain (6 % cement, sample 2)



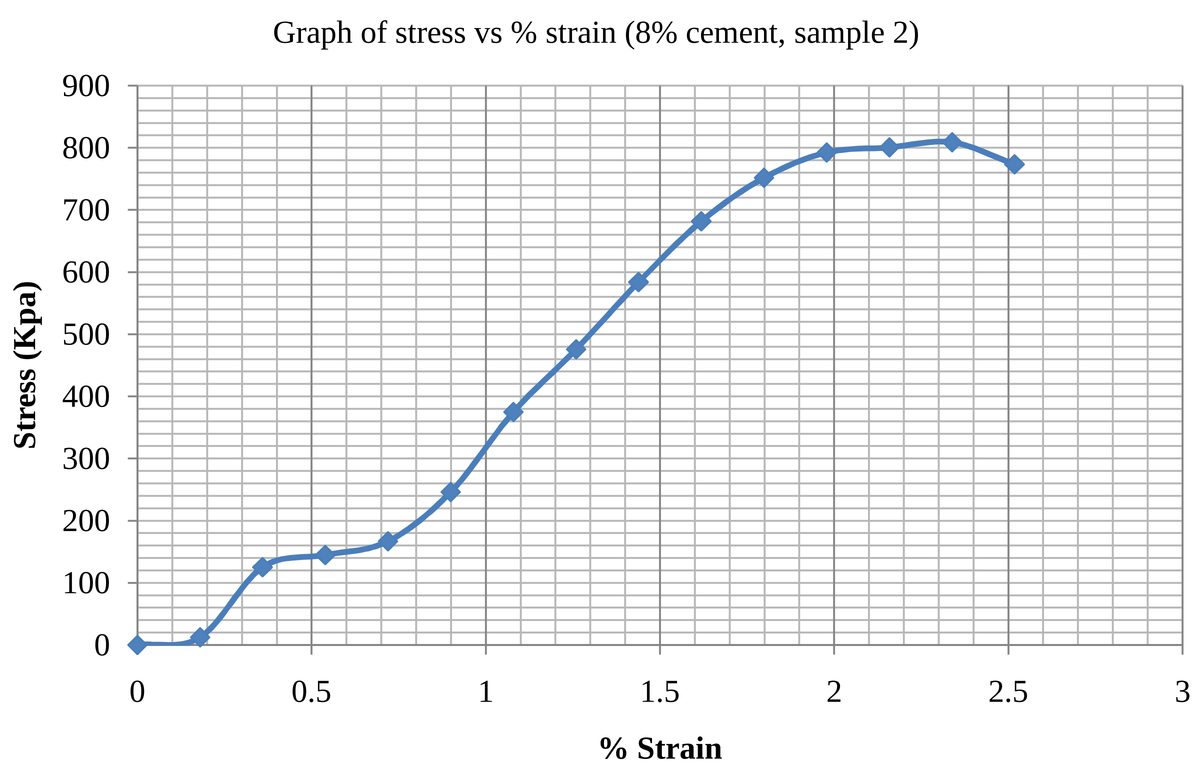
Results for 6% cement treated UCS samples (sample 3)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.03	0.2	0.002	0.180	0.002099	0.016	7.518672
40	0.05	0.4	0.004	0.360	0.002103	0.026	12.50854
60	0.06	0.6	0.005	0.540	0.002106	0.032	14.98316
80	0.11	0.8	0.007	0.719	0.00211	0.058	27.41945
100	0.18	1	0.009	0.899	0.002114	0.095	44.7869
120	0.29	1.2	0.011	1.079	0.002118	0.153	72.02572
140	0.42	1.4	0.013	1.259	0.002122	0.221	104.1235
160	0.54	1.6	0.014	1.439	0.002126	0.284	133.6292
180	0.74	1.8	0.016	1.619	0.002129	0.389	182.7873
200	0.96	2	0.018	1.799	0.002133	0.505	236.6959
220	1.18	2.2	0.020	1.978	0.002137	0.621	290.4059
240	1.45	2.4	0.022	2.158	0.002141	0.763	356.1999
260	1.75	2.6	0.023	2.338	0.002145	0.921	429.1062
280	1.95	2.8	0.025	2.518	0.002149	1.026	477.2664
300	2.11	3	0.027	2.698	0.002153	1.110	515.4739
320	2.25	3.2	0.029	2.878	0.002157	1.184	548.6599
340	2.35	3.4	0.031	3.058	0.002161	1.236	571.9836
360	2.41	3.6	0.032	3.237	0.002165	1.268	585.4991
380	2.45	3.8	0.034	3.417	0.002169	1.289	594.1106
400	2.35	4	0.036	3.597	0.002173	1.236	568.8
420	2.1	4.2	0.038	3.777	0.002177	1.105	507.341



Results for 8% cement treated UCS samples (sample 1)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.02	0.2	0.002	0.180	0.002099	0.011	5.012448
40	0.04	0.4	0.004	0.360	0.002103	0.021	10.00683
60	0.05	0.6	0.005	0.540	0.002106	0.026	12.48596
80	0.16	0.8	0.007	0.719	0.00211	0.084	39.88283
100	0.25	1	0.009	0.899	0.002114	0.132	62.20403
120	0.37	1.2	0.011	1.079	0.002118	0.195	91.89489
140	0.51	1.4	0.013	1.259	0.002122	0.268	126.4356
160	0.89	1.6	0.014	1.439	0.002126	0.468	220.2407
180	1.4	1.8	0.016	1.619	0.002129	0.736	345.8138
200	2	2	0.018	1.799	0.002133	1.052	493.1165
220	2.5	2.2	0.020	1.978	0.002137	1.315	615.2667
240	3.03	2.4	0.022	2.158	0.002141	1.594	744.335
260	3.41	2.6	0.023	2.338	0.002145	1.794	836.1441
280	3.73	2.8	0.025	2.518	0.002149	1.962	912.9249
300	3.8	3	0.027	2.698	0.002153	1.999	928.3415
320	3.64	3.2	0.029	2.878	0.002	1.915	887.6098

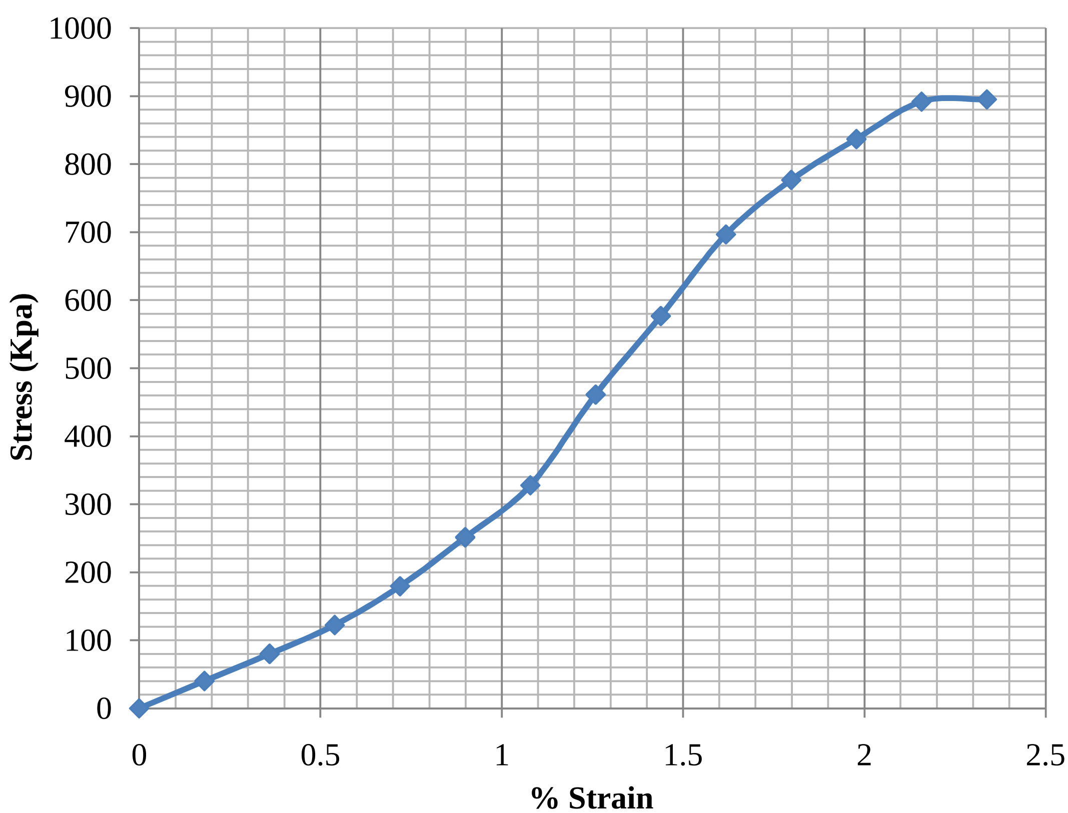


Results for 8% cement treated UCS samples (sample 2)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.05	0.2	0.002	0.180	0.002099	0.026	12.53112
40	0.5	0.4	0.004	0.360	0.002103	0.263	125.0854
60	0.58	0.6	0.005	0.540	0.002106	0.305	144.8372
80	0.67	0.8	0.007	0.719	0.00211	0.352	167.0094
100	0.99	1	0.009	0.899	0.002114	0.521	246.328
120	1.51	1.2	0.011	1.079	0.002118	0.794	375.0305
140	1.92	1.4	0.013	1.259	0.002122	1.010	475.9929
160	2.36	1.6	0.014	1.439	0.002126	1.241	584.0089
180	2.76	1.8	0.016	1.619	0.002129	1.452	681.7472
200	3.05	2	0.018	1.799	0.002133	1.604	752.0027
220	3.22	2.2	0.020	1.978	0.002137	1.694	792.4636
240	3.26	2.4	0.022	2.158	0.002141	1.715	800.8357
260	3.3	2.6	0.023	2.338	0.002145	1.736	809.1717
280	3.16	2.8	0.025	2.518	0.002149	1.662	773.4163

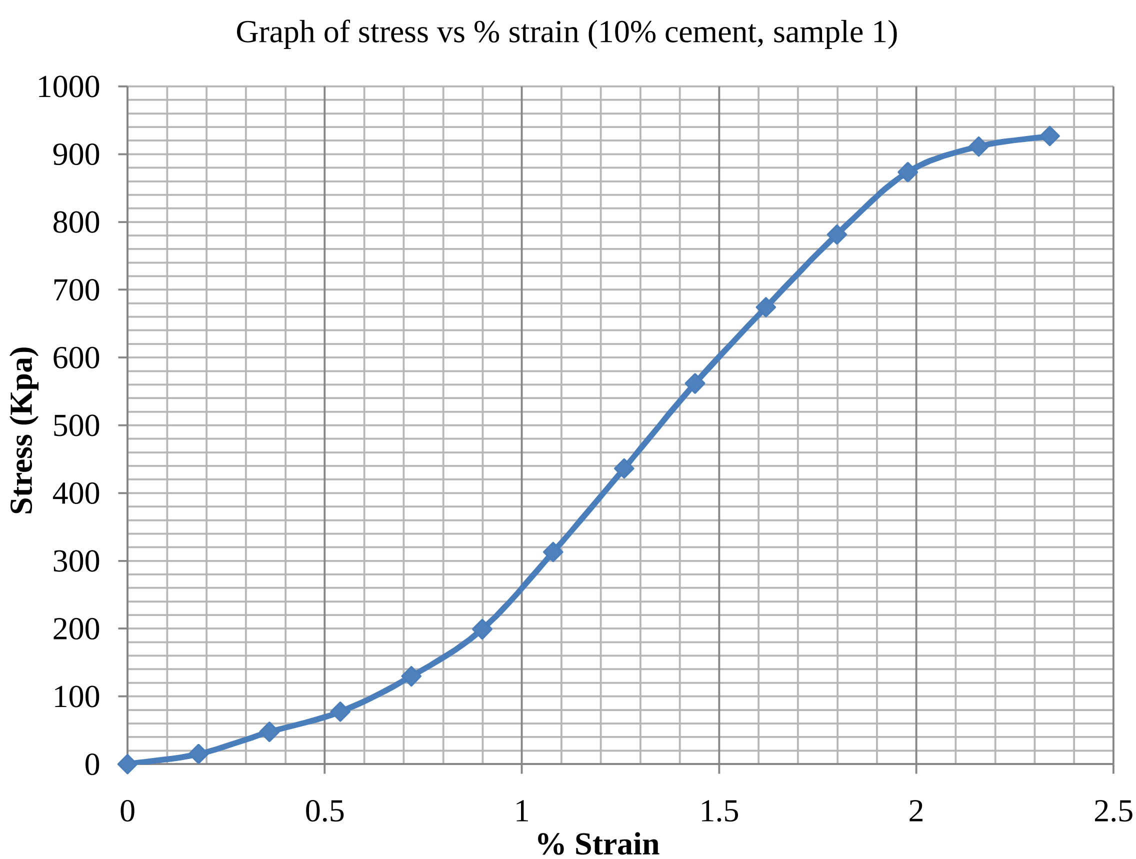


Results for 8% cement treated UCS samples (sample 3)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.16	0.2	0.002	0.180	0.002099	0.084	40.09959
40	0.32	0.4	0.004	0.360	0.002103	0.168	80.05467
60	0.49	0.6	0.005	0.540	0.002106	0.258	122.3624
80	0.72	0.8	0.007	0.719	0.00211	0.379	179.4727
100	1.01	1	0.009	0.899	0.002114	0.531	251.3043
120	1.32	1.2	0.011	1.079	0.002118	0.694	327.8412
140	1.86	1.4	0.013	1.259	0.002122	0.978	461.1181
160	2.33	1.6	0.014	1.439	0.002126	1.226	576.5851
180	2.82	1.8	0.016	1.619	0.002129	1.483	696.5677
200	3.15	2	0.018	1.799	0.002133	1.657	776.6585
220	3.4	2.2	0.020	1.978	0.002137	1.788	836.7628
240	3.63	2.4	0.022	2.158	0.002141	1.909	891.7281
260	3.65	2.6	0.023	2.338	0.002145	1.920	894.993

Graph of stress vs % strain (8% cement, sample 3)

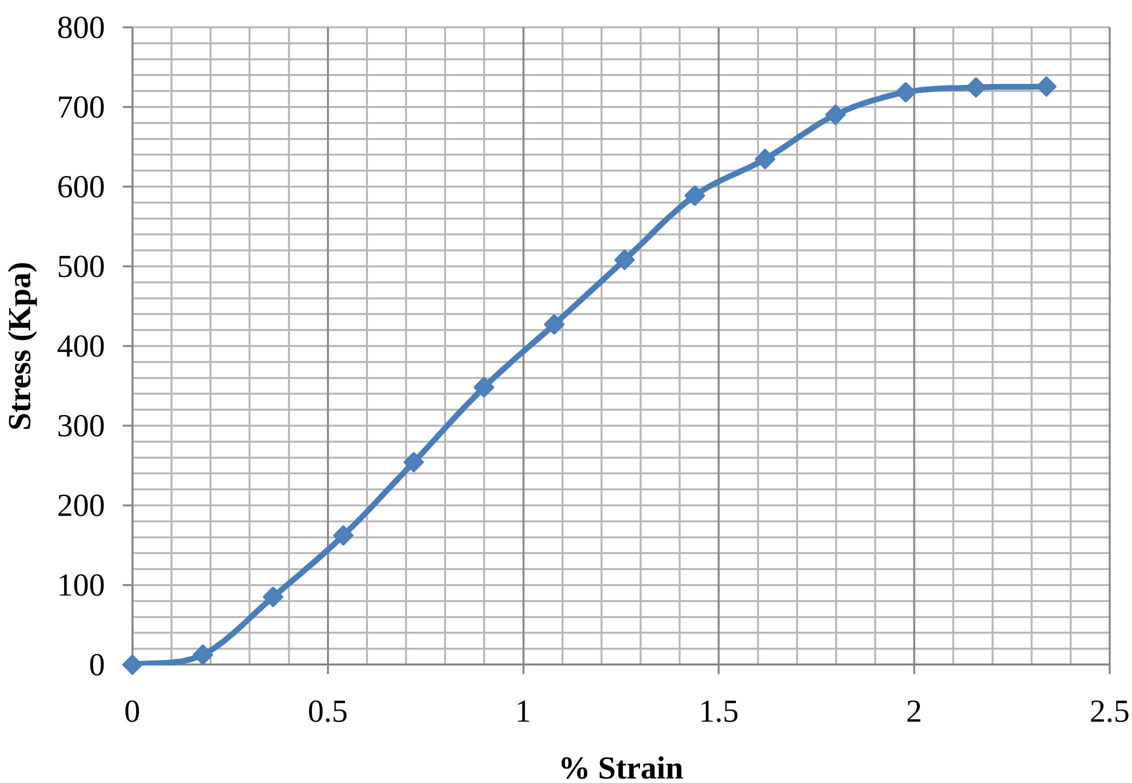


Results for 10% cement treated UCS samples (sample 1)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.06	0.2	0.002	0.180	0.002099	0.032	15.03734
40	0.19	0.4	0.004	0.360	0.002103	0.100	47.53246
60	0.31	0.6	0.005	0.540	0.002106	0.163	77.41297
80	0.52	0.8	0.007	0.719	0.00211	0.274	129.6192
100	0.8	1	0.009	0.899	0.002114	0.421	199.0529
120	1.26	1.2	0.011	1.079	0.002118	0.663	312.9393
140	1.76	1.4	0.013	1.259	0.002122	0.926	436.3268
160	2.27	1.6	0.014	1.439	0.002126	1.194	561.7374
180	2.73	1.8	0.016	1.619	0.002129	1.436	674.3369
200	3.17	2	0.018	1.799	0.002133	1.667	781.5897
220	3.55	2.2	0.020	1.978	0.002137	1.867	873.6788
240	3.71	2.4	0.022	2.158	0.002141	1.951	911.3805
260	3.78	2.6	0.023	2.338	0.002145	1.988	926.8694

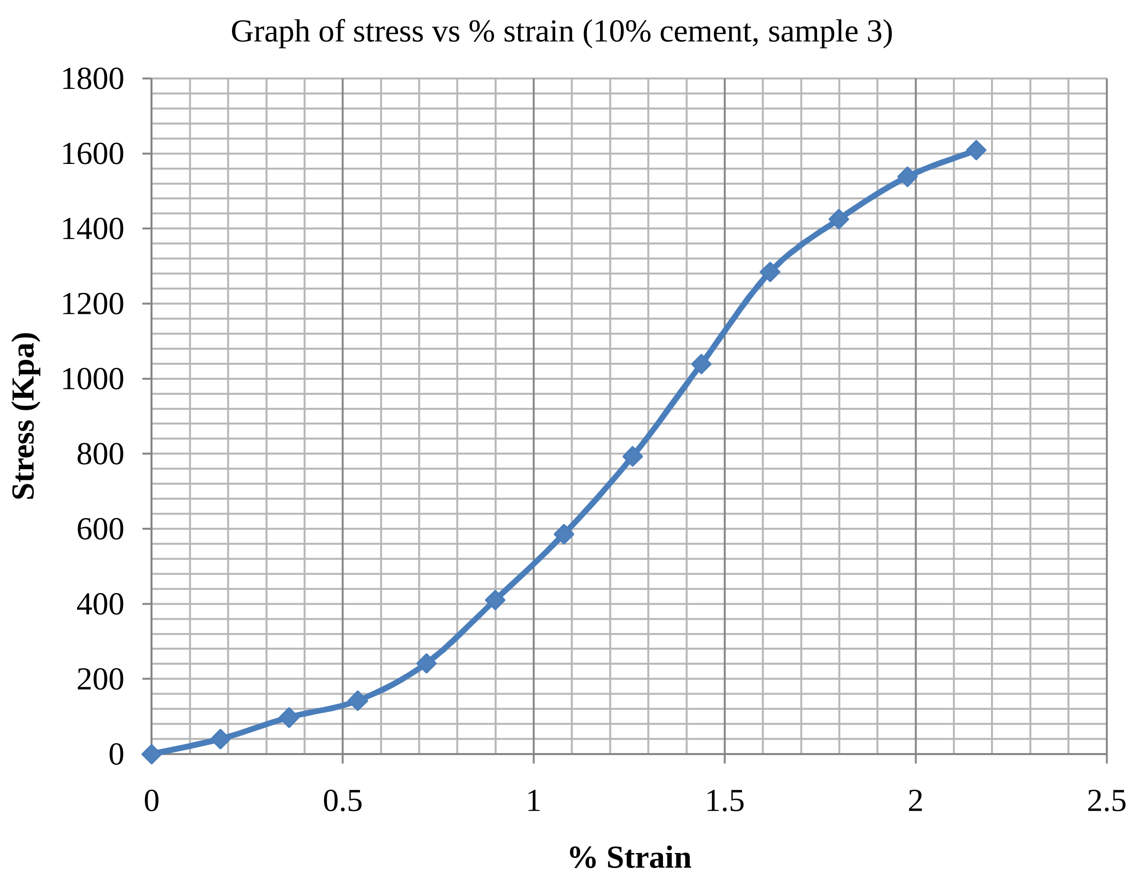


Results for 10% cement treated UCS samples (sample 2)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.05	0.2	0.002	0.180	0.002099	0.026	12.53112
40	0.34	0.4	0.004	0.360	0.002103	0.179	85.05809
60	0.65	0.6	0.005	0.540	0.002106	0.342	162.3175
80	1.02	0.8	0.007	0.719	0.00211	0.537	254.2531
100	1.4	1	0.009	0.899	0.002114	0.736	348.3426
120	1.72	1.2	0.011	1.079	0.002118	0.905	427.187
140	2.05	1.4	0.013	1.259	0.002122	1.078	508.2216
160	2.38	1.6	0.014	1.439	0.002126	1.252	588.9582
180	2.57	1.8	0.016	1.619	0.002129	1.352	634.8153
200	2.8	2	0.018	1.799	0.002133	1.473	690.3631
220	2.92	2.2	0.020	1.978	0.002137	1.536	718.6315
240	2.95	2.4	0.022	2.158	0.002141	1.552	724.6826
260	2.96	2.6	0.023	2.338	0.002145	1.557	725.8025

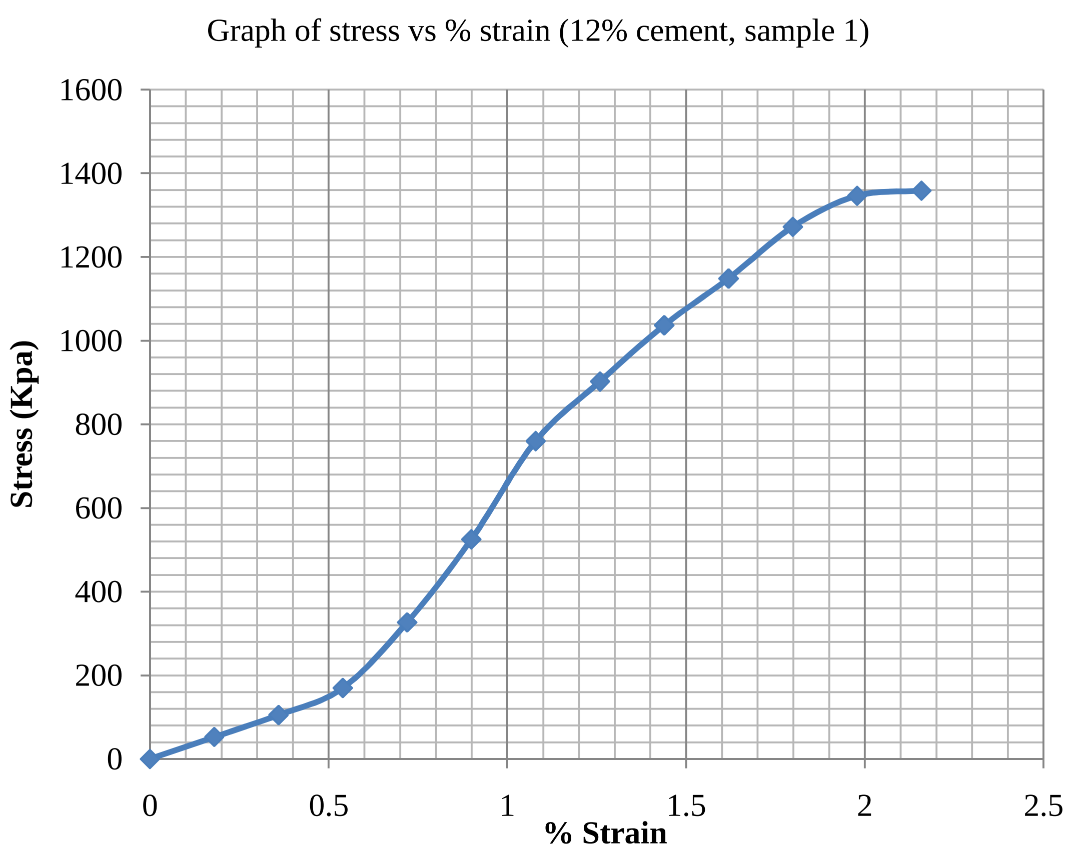
Graph of stress vs % strain (10% cement, sample 2)



Results for 10% cement treated UCS samples (sample 3)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.16	0.2	0.002	0.180	0.002099	0.084	40.09959
40	0.39	0.4	0.004	0.360	0.002103	0.205	97.56663
60	0.57	0.6	0.005	0.540	0.002106	0.300	142.34
80	0.97	0.8	0.007	0.719	0.00211	0.510	241.7897
100	1.65	1	0.009	0.899	0.002114	0.868	410.5466
120	2.36	1.2	0.011	1.079	0.002118	1.241	586.1403
140	3.2	1.4	0.013	1.259	0.002122	1.683	793.3215
160	4.2	1.6	0.014	1.439	0.002126	2.209	1039.338
180	5.2	1.8	0.016	1.619	0.002129	2.735	1284.451
200	5.78	2	0.018	1.799	0.002133	3.040	1425.107
220	6.25	2.2	0.020	1.978	0.002137	3.288	1538.167
240	6.55	2.4	0.022	2.158	0.002141	3.445	1609.041

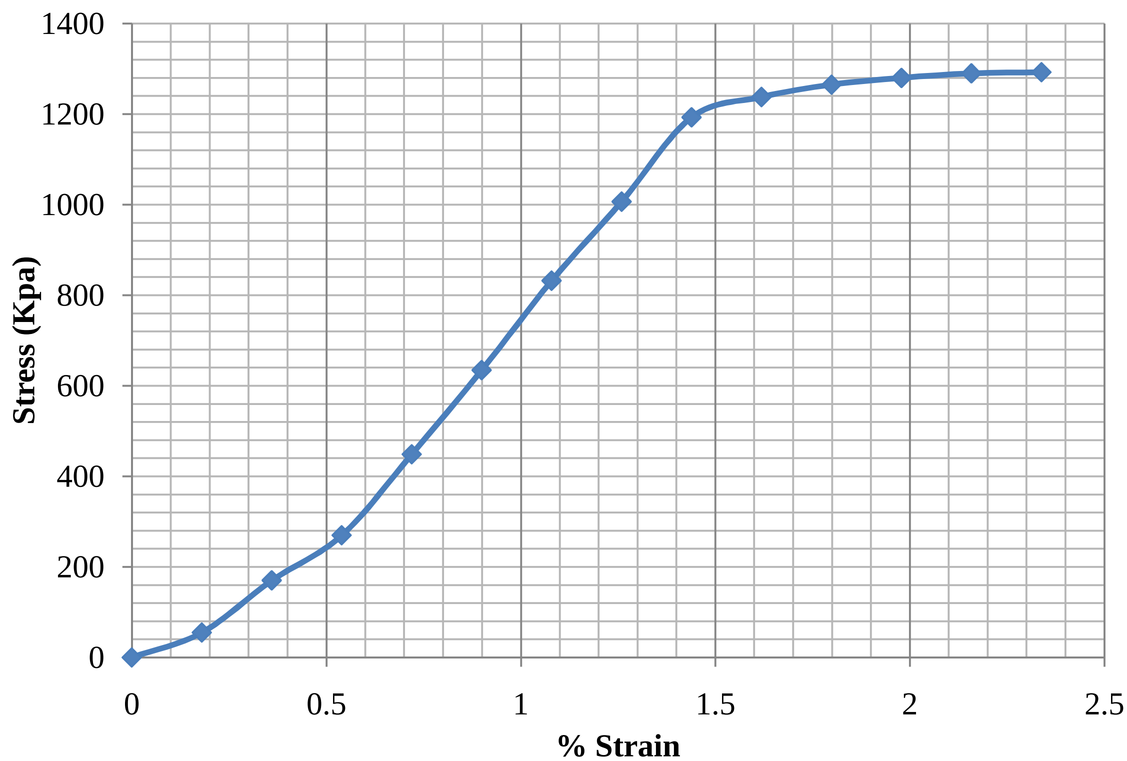


Results for 12% cement treated UCS samples (sample 1)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.21	0.2	0.002	0.180	0.002099	0.110	52.63
40	0.42	0.4	0.004	0.360	0.002103	0.221	105.07
60	0.68	0.6	0.005	0.540	0.002106	0.358	169.81
80	1.31	0.8	0.007	0.719	0.00211	0.689	326.54
100	2.11	1	0.009	0.899	0.002114	1.110	525.00
120	3.06	1.2	0.011	1.079	0.002118	1.610	760.00
140	3.64	1.4	0.013	1.259	0.002122	1.915	902.40
160	4.19	1.6	0.014	1.439	0.002126	2.204	1036.86
180	4.65	1.8	0.016	1.619	0.002129	2.446	1148.60
200	5.16	2	0.018	1.799	0.002133	2.714	1272.24
220	5.47	2.2	0.020	1.978	0.002137	2.877	1346.20
240	5.53	2.4	0.022	2.158	0.002141	2.909	1358.47



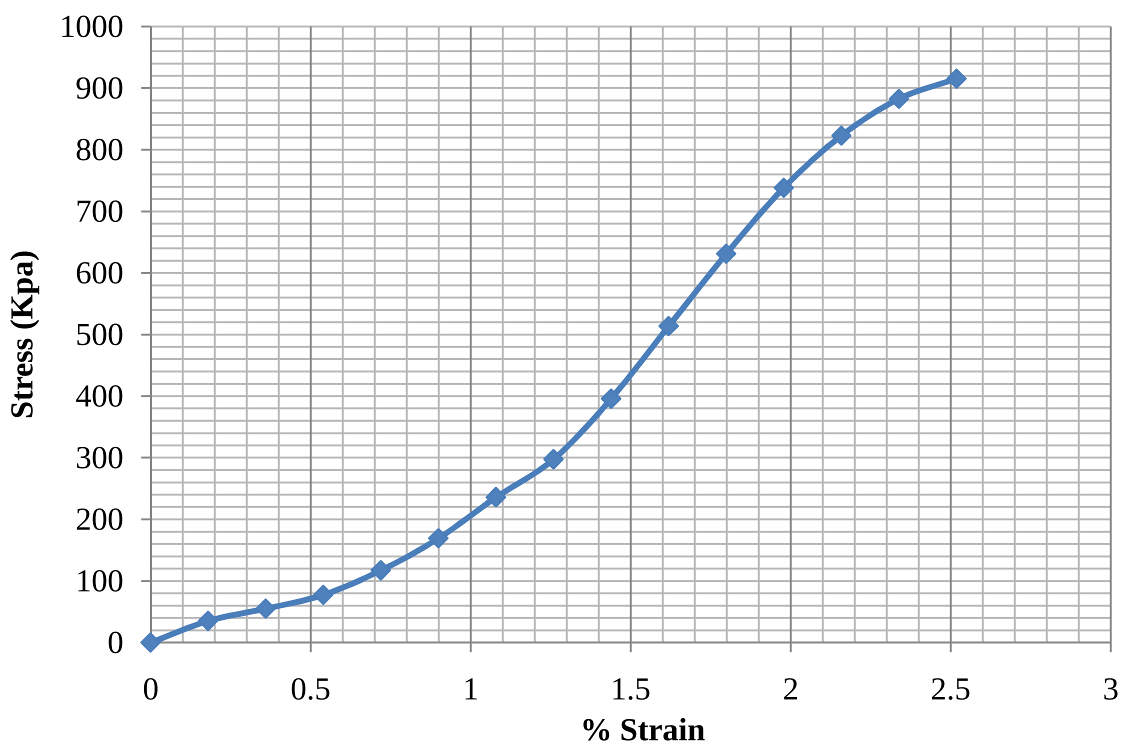
Results for 12% cement treated UCS samples (sample 2)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.22	0.2	0.002	0.180	0.002099	0.116	55.13693
40	0.68	0.4	0.004	0.360	0.002103	0.358	170.1162
60	1.08	0.6	0.005	0.540	0.002106	0.568	269.6968
80	1.8	0.8	0.007	0.719	0.00211	0.947	448.6819
100	2.55	1	0.009	0.899	0.002114	1.341	634.4811
120	3.35	1.2	0.011	1.079	0.002118	1.762	832.0213
140	4.06	1.4	0.013	1.259	0.002122	2.136	1006.527
160	4.82	1.6	0.014	1.439	0.002126	2.535	1192.764
180	5.01	1.8	0.016	1.619	0.002129	2.635	1237.519
200	5.13	2	0.018	1.799	0.002133	2.698	1264.844
220	5.2	2.2	0.020	1.978	0.002137	2.735	1279.755
240	5.25	2.4	0.022	2.158	0.002141	2.762	1289.689
260	5.27	2.6	0.023	2.338	0.002145	2.772	1292.223

Graph of stress vs % strain (12% cement, sample 2)



Results for 12% cement treated UCS samples (sample 3)							
Deformation Dial Reading	Load Dial Reading	Sample Deformation	Strain	% strain	Corrected Area A'	Load (KN)	Stress (Kpa)
0	0	0	0	0	0.0021	0	0
20	0.14	0.2	0.002	0.180	0.002099	0.074	35.08714
40	0.22	0.4	0.004	0.360	0.002103	0.116	55.03759
60	0.31	0.6	0.005	0.540	0.002106	0.163	77.41297
80	0.47	0.8	0.007	0.719	0.00211	0.247	117.1558
100	0.68	1	0.009	0.899	0.002114	0.358	169.195
120	0.95	1.2	0.011	1.079	0.002118	0.500	235.9463
140	1.2	1.4	0.013	1.259	0.002122	0.631	297.4956
160	1.6	1.6	0.014	1.439	0.002126	0.842	395.9383
180	2.08	1.8	0.016	1.619	0.002129	1.094	513.7805
200	2.56	2	0.018	1.799	0.002133	1.347	631.1892
220	3	2.2	0.020	1.978	0.002137	1.578	738.3201
240	3.35	2.4	0.022	2.158	0.002141	1.762	822.9447
260	3.6	2.6	0.023	2.338	0.002145	1.894	882.7328
280	3.74	2.8	0.025	2.518	0.002149	1.967	915.3724

Graph of stress vs % strain (12% cement, sample 3)



Appendix XI**:** Results of unconfined compression test

Results of Unconfined Compression test			
Soil mix	Sample no.	Unconfined compressive strength (Kpa)	Average compressive strength (Kpa)
Black cotton soil (BCS)	1	255.33	268.14
	2	280.95	
	3	0	
Black cotton soil (BCS) + 6% Cement	1	823.5	734.33
	2	785.37	
	3	594.11	
Black cotton soil (BCS) + 8% Cement	1	926.87	849.22
	2	725.8	
	3	894.99	
Black cotton soil (BCS) + 10% Cement	1	926.87	1087.24
	2	725.8	
	3	1609.04	
Black cotton soil (BCS) + 12% Cement	1	1358.47	1188.69
	2	1292.22	
	3	915.37	

Appendix XII**:** Compaction test analysis for soil stabilized with cement and RHA

	COMPACTION TEST RESULTS					
Mix		**MDD and OMC**				
	MDD (Kg/m^3)	1176	1220	1237	1197	1189
7%C + 2.5%RHA	OMC (%)	21.91	24.77	26.98	34.18	34.63
	MDD (Kg/m^3)	1173	1206	1162	1100	1054
6%C + 5%RHA	OMC (%)	28.41	30.18	35.71	41.88	44.84
	MDD (Kg/m^3)	1162	1174	1148	1088	1045
5%C + 7.5%RHA	OMC (%)	27.85	31.77	35.56	41.28	45.45
	MDD (Kg/m^3)	1144	1168	1149	1120	1038
4%C + 10%RHA	OMC (%)	25.87	32.11	36.45	40.11	46.29
	MDD (Kg/m^3)	1123	1137	1104	1065	1014
3%C + 12.5%RHA	OMC (%)	31.41	35.00	39.51	43.97	48.31
	MDD (Kg/m^3)	1078	1089	1097	1041	1022
2%C + 15%RHA	OMC (%)	33.05	36.43	39.08	43.76	46.00
	MDD (Kg/m^3)	1055	1073	1083	1040	1012
1%C + 17.5%RHA	OMC (%)	31.65	35.45	40.01	43.36	47.16
	MDD (Kg/m^3)	1028	1038	1055	1031	1006
0%C + 20%RHA	OMC (%)	32.26	35.07	41.36	43.78	46.53

Appendix XIII**:** MDD and OMC for soil, cement and rice husk ash mix

COMPACTION TEST ANALYSIS		
Mix	**MDD (Kg/m^3)**	**OMC (%)**
7%C + 2.5%RHA	1238	26.5
6%C + 5%RHA	1206	29.9
5%C + 7.5%RHA	1175	31.4
4%C + 10%RHA	1169	32.4
3%C + 12.5%RHA	1138	34.5
2%C + 15%RHA	1100	38.4
1%C + 17.5%RHA	1085	39.3
0%C + 20%RHA	1056	41.1

Appendix XIV**:** Compressive strength for cement and RHA stabilized soil blocks

Interlocking blocks made using black cotton soil and 7% cement with 2.5% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit Weight Kg/m^3	Compressive Strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	12112	70.5	1872.39	1.492	1.327
2	7	47250	6,468,750	10903.5	77.67	1685.57	1.644	
3	7	47250	6,468,750	10320	40	1595.36	0.847	
1	14	47250	6,468,750	11021	80	1703.73	1.693	1.834
2	14	47250	6,468,750	11138	90	1721.82	1.905	
3	14	47250	6,468,750	10539.5	90	1629.29	1.905	
1	28	47250	6,468,750	10315.5	140	1594.67	2.963	2.787
2	28	47250	6,468,750	10290	135	1590.72	2.857	
3	28	47250	6,468,750	10152.5	120	1569.47	2.540	

Interlocking blocks made using black cotton soil and 6% cement with 5% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit Weight (Kg/m^3)	Compressive Strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10503	38.9	1623.65	0.823	1.025
2	7	47250	6,468,750	10893	47	1683.94	0.995	
3	7	47250	6,468,750	10919.5	59.34	1688.04	1.256	
1	14	47250	6,468,750	10696	62	1653.49	1.312	1.228
2	14	47250	6,468,750	10215	55	1579.13	1.164	
3	14	47250	6,468,750	10307.5	57	1593.43	1.206	
1	28	47250	6,468,750	10029.5	117.3	1550.45	2.481	2.617
2	28	47250	6,468,750	10433.5	134.3	1612.91	2.841	
3	28	47250	6,468,750	10096	119.5	1560.73	2.529	

Interlocking blocks made using black cotton soil and 5% cement with 7.5% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10940	39	1691.21	0.825	0.894
2	7	47250	6,468,750	10638	35	1644.52	0.741	
3	7	47250	6,468,750	10824	52.67	1673.28	1.115	
1	14	47250	6,468,750	10693	50	1653.02	1.058	1.038
2	14	47250	6,468,750	10354	45	1600.62	0.952	
3	14	47250	6,468,750	10792	52.13	1668.33	1.103	
1	28	47250	6,468,750	10308	125.0	1593.51	2.646	2.575
2	28	47250	6,468,750	10809.5	130	1671.03	2.751	
3	28	47250	6,468,750	9914.5	110	1532.68	2.328	

Interlocking blocks made using black cotton soil and 4% cement with 10% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10357.5	28	1601.16	0.593	0.748
2	7	47250	6,468,750	9980	25.33	1542.80	0.536	
3	7	47250	6,468,750	10808.5	52.67	1670.88	1.115	
1	14	47250	6,468,750	10399	42.63	1607.57	0.902	0.981
2	14	47250	6,468,750	10553.5	45.38	1631.46	0.960	
3	14	47250	6,468,750	10243	51	1583.46	1.079	
1	28	47250	6,468,750	10001.5	101.9	1546.13	2.156	2.039
2	28	47250	6,468,750	9598	85	1483.75	1.799	
3	28	47250	6,468,750	10428	102.1	1612.06	2.161	

Interlocking blocks made using black cotton soil and 3% cement with 12.5% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10549.5	25	1630.84	0.529	0.504
2	7	47250	6,468,750	10275	24	1588.41	0.508	
3	7	47250	6,468,750	10121	22.5	1564.60	0.476	
1	14	47250	6,468,750	10315.5	29.25	1594.67	0.619	0.596
2	14	47250	6,468,750	9983	27.25	1543.27	0.577	
3	14	47250	6,468,750	10164.5	28	1571.32	0.593	
1	28	47250	6,468,750	8974	85	1387.29	1.799	1.825
2	28	47250	6,468,750	9944.5	90	1537.31	1.905	
3	28	47250	6,468,750	9665	83.75	1494.11	1.772	

Interlocking blocks made using black cotton soil and 2% cement with 15% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10715	19.67	1656.43	0.416	0.402
2	7	47250	6,468,750	10317.5	23	1594.98	0.487	
3	7	47250	6,468,750	10189.5	14.33	1575.19	0.303	
1	14	47250	6,468,750	9247	28	1429.49	0.593	0.613
2	14	47250	6,468,750	10449	28.88	1615.30	0.611	
3	14	47250	6,468,750	10635.5	30	1644.14	0.635	
1	28	47250	6,468,750	9867	100	1525.33	2.116	1.790
2	28	47250	6,468,750	9605.5	78.75	1484.91	1.667	
3	28	47250	6,468,750	8930.5	75	1380.56	1.587	

Interlocking blocks made using black cotton soil and 1% cement with 17.5% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	9572	16.5	1479.73	0.349	0.375
2	7	47250	6,468,750	10047	17.83	1553.16	0.377	
3	7	47250	6,468,750	9535	18.8	1474.01	0.399	
1	14	47250	6,468,750	9256	30	1430.88	0.635	0.594
2	14	47250	6,468,750	8990.5	25	1389.84	0.529	
3	14	47250	6,468,750	9056.5	29.3	1400.04	0.619	
1	28	47250	6,468,750	9264.5	65	1432.19	1.376	1.312
2	28	47250	6,468,750	8684	60	1342.45	1.270	
3	28	47250	6,468,750	8607.5	61	1330.63	1.291	

Interlocking blocks made using black cotton soil and 0% cement with 20% RHA								
S. No.	Age (days)	Area (mm^2)	Volume (mm^3)	Weight (gm)	Load (KN)	Unit weight (Kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
1	7	47250	6,468,750	10070	22.8	1556.71	0.483	0.434
2	7	47250	6,468,750	10094.5	19	1560.50	0.402	
3	7	47250	6,468,750	9715	19.7	1501.84	0.416	
1	14	47250	6,468,750	9093.5	26.5	1405.76	0.561	0.466
2	14	47250	6,468,750	9227	20	1426.40	0.423	
3	14	47250	6,468,750	9333	19.5	1442.78	0.413	
1	28	47250	6,468,750	8760.5	60.75	1354.28	1.286	1.451
2	28	47250	6,468,750	8512	55	1315.86	1.164	
3	28	47250	6,468,750	8719	90	1347.86	1.905	