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Research Paper

EFFECT OF HAND COMPACTION ON COMPRESSIVE STRENGTH AND WATER ABSORPTION OF COMPRESSED STABILIZED EARTH BLOCKS

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Stabilized earth is an alternative building material which is significantly cheaper than using conventional concrete, and is also environmentally sustainable. In this research, three types of soil were used: murram, red coffee and black cotton soil. Experimental work has delved into basic material properties, as well as strength tests on specimens. Accordingly, the research work has conducted numerous tests such as atteberg limit, particle density, particle size distribution (both wet sieving and hydrometer method), compaction and linear shrinkage on material as well as strength test on blocks. The percentage of stabilizers used were 4% and 6% for cement, 4% for lime, 63% sand (on black cotton and red coffee soil) then 20% of sand on murram soil. From the result, the blocks made with 6% of cement had a highest strength and when using different method (2 layers of hand compaction before using the compress machine on the third layer) to compress blocks, the compressive strength at 28 days increase from 3 MPa to 4.3 MPa for black cotton soil, from 3.9 MPa to 5.2 MPa for red coffee soil and from 4.4 MPa to 6.2 MPa for murram soil. The blocks using 2 layers of hand compaction before using the compress machine on the third layer were resistant to water than other.

Keywords: Black cotton soil, Red coffee soil, Murram soil, Hand compaction, Compressive strength, Water absorption

INTRODUCTION

Historically earth was used as a construction material all over the world. It is therefore the most widely used building material throughout most developing countries: it is cheap, available in abundance, and simple to form into building elements (Adam and Agib, 2001).

The potential for using earth as an alternatives construction material have being seriously considered since earth has been used as a brick in house construction throughout the ages (Nasly *et al.*, 2009). However, earth is more routinely used in the construction of modern, sustainable buildings, its material properties

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and production processes must be properly quantified (Steve, 2010). The soil properties can be modified by adding another material to improve its durability. According to Nasly *et al.* (2009), when a soil is successfully stabilized one or more of the following effects will be evident: Increase in the strength, reduction in the permeability of the soil, the resulting soil will be made water repellent, Increase in the durability of the soil, less shrinkage and expansion of the resulting soil in dry and wet conditions.

The various methods of stabilisation depend on the action in which the stabilizers are acting. This action may be mechanical (compaction), physical (fiber or by modifying the grain size) and physicochemical (hydrophobic zing agents, binder) according to (Chaibeddra and Kharchi, 2013). Meanwhile, the effectiveness of stabilization depends on the ability to obtain uniformity in blending the various materials (Olaniyan *et al.,* 2011). Adobe mud blocks are one of the oldest and most widely used building materials (Grytan *et al.*, 2012). The new development with earth construction started with the technology of Compressed Stabilized Earth Blocks (CSEB) (Asmamaw, 2007). Stabilized compressed earth block is an innovative advancement of the traditional earth technology and involves adding a little quantity of stabilizer such as cement to earth and making compressed earth blocks. According to Fetra *et al.* (2011), CSEB offered numbers of advantages: it increases the utilization of local material and reduces the transportation cost as the production is in situ, makes quality housing available to more people, and generates local economy rather than spending for import materials. The quality of the block depends on the properties and mix of soil types, the amount of force applied for compaction, and the addition of chemical or natural products to further stabilize and strengthen the blocks (UN-HABITAT, 2009). According to USAID (2012) the good soil for stabilisation should content 60-70% sand and 30-40% clay.

Many researchers had focused their work on compressed stabilized earth block. Walker (1997) studied the influence of soil characteristics and cement content on the physical properties of stabilised bricks. He mixed two soil types together, one a clay soil with 50% clay content and a river soil with 1% clay content to get a combination of soil properties. A manually operated machined was used to press blocks, under compaction pressures of 4 MPa. Both saturated and dry unconfined compressive strength testing was undertaken. Shrinkage was assessed using a 200 mm demec gauge. Dry compressive strength ranged between 5.54 MPa and 3 MPa whilst saturated compressive 0.95 and 3.2 MPa. Compressive strengths varied largely depending on the clay content. Walker concluded that clays have a uniaxial dry compressive strength which is lost with saturation. Drying shrinkage of the blocks is primarily governed by plasticity index of the parent soil. Once the plasticity index exceeded 20, there is a steady increase in drying shrinkage with increasing clay content. Cement acts to bond soil particles together whereas clay minerals disrupt cement bonding.

From the literature, the addition of cement in compressed earth block increase the compressive strength of block. The water absorption capacity reduces with lowest clay content in soil. Due to the high cost of cement used in the process of stabilised blocks production, the amount of cement used can be reduced by the use of materials such as Fly Ash, lime, quarry dust as well as sand which the percentage vary depending on the type of soil. The main objective of this work is to compare the compressive strength of block produce using 2 layers hand compaction and compressive machine on the third layer to the compressive strength of block produced using compressed machine.

MATERIALS AND METHODS USED

Materials used in this study include black cotton soil, red coffee soil, murram soil, river sand, cement and lime from a local factory. Basic material properties were determined, after which the materials were used to develop the stabilized blocks which were further investigated in line with the key research objective.

Black Cotton Soil

Black cotton soil is classified as an expansive soil and is usually poor in engineering properties (osinubi *et al.*, 2011). Dark or black in color, it has approximately sixty percent (60%) of expansive clay known as montmorillonite that forms deep cracks in drier seasons or years (Eliud, 2010). Massive expansion and contraction of the clay minerals takes place Due to the wetting and drying. These contraction leads to the formation of the wide and deep cracks that close after rain when the clay minerals swell.

Red Coffee Soil

Red soils generally form from iron-rich sedimentary rock. They are usually poor for agricultural farming, as it is low in nutrients and humus and difficult to cultivate. The texture of red soils varies from sand to clay, the majority being loams. Their other characteristics include porous and friable structure.

Murram or Laterite Soil

Murram or Laterite is a red soil rich in iron oxide. Laterite usually derived from wide variety of rock weathering under strongly oxidizing and leaching conditions (Raheem *et al.,* 2010).

Sand

The sand used was river sand with a maximum aggregate size of 5 mm

Cement

The cement of nominal strength 32.5 MPa meeting Kenya standard (KS18-1:2001) from BAMBURI CEMENT (Kenya) was used. Bamburi Cement Limited is East Africa's leading Cement producer and is a member of the Lafarge Group - the world's largest building materials group. Nguvu CEM IV/B (P) 32,5 N is formulated from Cement Clinker and interground with other constituents, mainly natural Pozzolana, in accordance to the requirements of European Standards (EN 197 Part 1) Composition, Specification and Conformity criteria for Common Cements. Nguvu CEM IV/B(P) 32,5 N is characterized by good early and 28 day strengths and fast setting.

Lime

Lime is a versatile product manufactured from a very high calcium burnt limestone. It is majorly applied in industrial effluent treatment, soil acidity correction and soil stabilization in road constructions. The lime use was obtained from Rhino Lime Manufactured at Kaloleni Lime and Cement Works Kaloleni a Division of Athi River Miming Ltd.

Testing Method

The physical properties of the soil materials were obtained based on fundamental soil test undertaken in accordance to BS 1377 (ref: BS 1377, part 2 and 4, 1990). The Physical properties that were determined were: Moisture content, bulk density, Atteberg limits, linear shrinkage, sieve analysis (wet sieving), particle density and compaction. The compaction was done on mixtures of soil and a variable sand proportion of 60%, 63% and 65% for black cotton and red coffee soil then 20%, 50% and 60% for murram soil in order to investigate the effect of sand on dry density of black cotton soils. The optimum moisture content of the mixture which gave the good dry density was used for blocks production.

Casting Procedure

Two (2) phases of block were produced: In phase one (1), the mixture sand-soil (63% sand on Black Cotton Soil (BCS) and Red Coffee Soil (RCS), 20% sand on Murram Soil (MS) which has the highest value of optimum dry density from compaction test were chosen to produce blocks in addition to the control: blocks produce with pure soil without addition of sand, then different percentage (4% and 6%) of cement and 4% of lime plus 2% of cement were used as chemical additive. At this phase, the blocks were compressed using compressive machine. In phase two (2), the composition of blocks was the same as in the phase 1, but the method used to compress blocks was different: two layers of hand compaction with 30 blows at each layer and the third layer were compressed using the compressive machine.

The different proportion of soil and stabilizer were weighted, mixed and water was added a little until the soil mixed achieves the consistency. It was ensured that this quantity of water was not very far from the OMC obtained during the compaction test. The mixture was filled into the mould and compacted. Then the blocks were kept in a curing place and were covered with polyethylene paper to facilitate curing and protection from external agents such as rain. For every mix prepared, the linear shrinkage was measured to determine the amount shrinkage, and the number of cracks that can occur for different type of blocks made from mix Table 1.

The dry compressive strength of the blocks was determined according to BS 1881 part 116, 1983, employing a Universal Testing Machine (UTM). During the compressive test, each block of nominal dimension 290 x 140 x 120 mm was weighed and aligned on the UTM, followed by gradual application of load until failure. Maximum applied load was recorded and used to calculate compressive strength.

RESULTS AND DISCUSSION

The Physical Properties of Different Type of Soil

Basic material properties are presented in Table 2 and Figure 1. From the Table 2, it is observed that the dry density of black cotton soil is 1283.63 kg/m^3 while red coffee soil and murram soil have a dry density of 1327.33 kg/

Table 1: Type of Mixture and Blocks Label

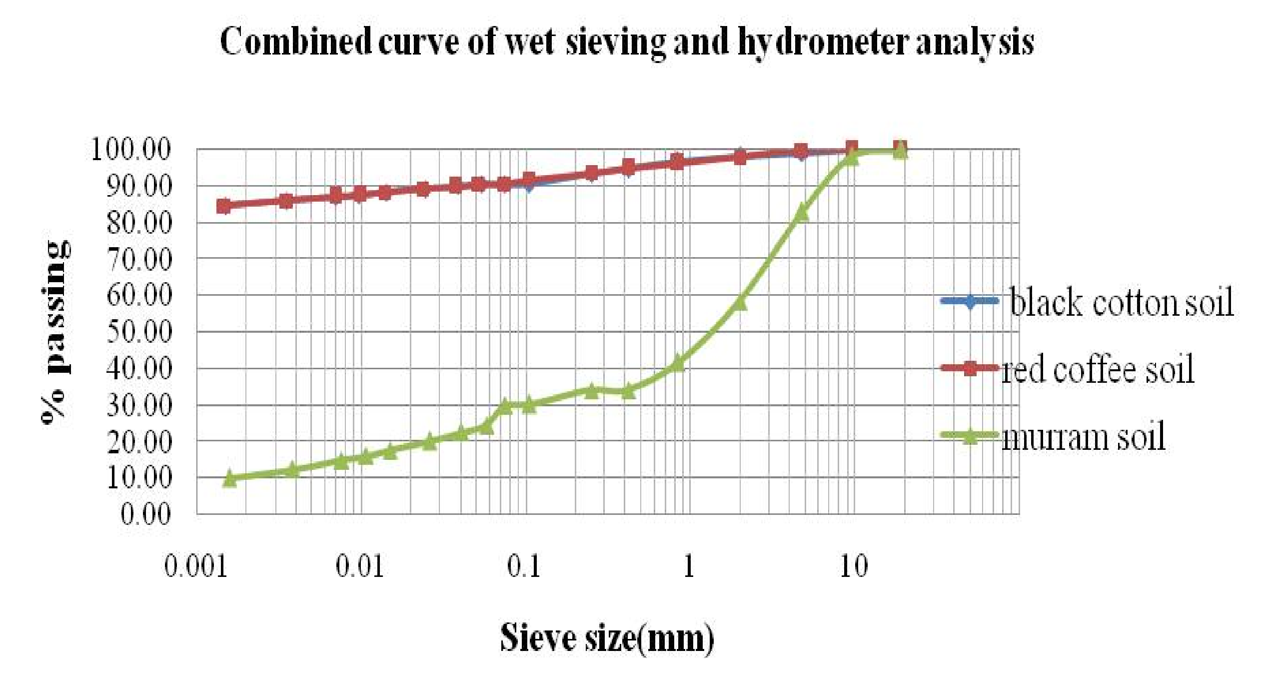
Composition of Mixture	Sample Label
Pure red coffee soil	RCS
Red coffee soil + 63% sand	RCS-63S
Red coffee soil + 63% sand + 4% cement	RCS-63S-4C
Red coffee soil +63% sand + 6% cement	RCS-63S-6C
Red coffee soil + 63% sand + 4% lime +2% cement	RCS-63S-4L-2C
Red coffee soil + 4%lime +2% cement	RCS-4L-2C
Pure murram soil	MS
Murram soil + 20% sand	MS-20S
Murram soil + 20% sand + 4% cement	MS-20S-4C
Murram soil + 20% sand + 6% cement	MS-20S-6C
Murram soil + 20% sand + 4% lime + 2% cement	MS-20S-4L-2C
Murram soil + 4% lime + 2% cement	MS-4L-2C
Pure black cotton soil	BCS
Black cotton soil + 63% sand	BCS-63S
Black cotton soil + 63% sand + 4% cement	BCS-63S-4C
Black cotton soil +63% sand + 6% cement	BCS-63S-6C
Black cotton soil + 63% sand + 4% lime +2% cement	BCS-63S-4L-2C
Black cotton soil + 4% lime + 2%cement	BCS-63S-4L-2C

m^3 and 1607.01 kg/m^3 respectively. In addition the plastic index of black cotton soil red soil and murram soil are 47%, 23 % and 20, respectively. However, Walker (1995) said that the best earth soils for stabilization are those with low plasticity index below 20% and those above are not suitable for manual compaction. Veena *et al.* (2014) confirmed this statement by saying: soils with a plasticity index above 20-25 are not suited to cement stabilization using manual presses, due to problems with excessive drying shrinkage, inadequate durability and low compressive strength. In view of this, it can be concluded that black cotton soil is predominantly a clayed type of soil. It is plastic and has a high affinity for water absorption; this combined with its high range of shrinkage limit confirms the need for enhancing of neat black cotton soil through stabilization if it were to be in the construction industry. Figure 1 gives the particle size distribution of black cotton soil, red coffee soil

Table 2: Physical Properties Black Cotton Soil, Red Coffee Soil And Murram Soil

Physical Properties	Black Cotton Soil	Red Coffee Soil	Murram Soil
Moisture content (%)	28	25	15
Liquid limit (%)	75	48	43
Plastic limit (%)	28	25	23
Plastic index (%)	47	23	20
Linear shrinkage (%)	19	17	11
Percentage of fin clay (%)	85.17	88.9	10.9
Percentage of fin slit (%)	5.33	1.5	13.9
Percentage of sand (%)	7.75	7.5	33.64
Percentage of gravel (%)	1.75	2.1	41.56
OMC (%)	25.5	26.5	16.31
Dry density (kg/m3)	1283.63	1327.33	1607.01
Specific gravity(g/m3)	1.310	2.261	2.507
classification	Clayed soil	Clayed soil	Gravel soil

Figure 1: Particle Size Distribution of Black Cotton Soil, Red Coffee Soil and Murram Soil



and murram soil. The particle size distribution is a combine result of both wet sieving and hydrometer method. In addition, it is observed that the 89% of the black cotton soil and red coffee soil were passing 0.075 mm, hence indicating the fine nature of the material. Murram soil is a gravel soil while black cotton soil and red coffee soil are clayed soil depending on the distribution of particle size along the curve. According to the ASTM (American Society for Testing and Materials), the particle classification boundaries is presented in Table 3.

Effect of Sand on Optimum Dry Density (ODD) and Optimum Moisture Content (OMC) of Black Cotton Soil, Red Coffee Soil and Murram Soil

According to USAID (United States Agency International Development, 2012), a good soil for good quality Stabilised Soil Blocks (SSB) must have 60-70% of sand with only 30-40% of clay. From the wet sieving test, black cotton soil and red coffee soil had 85.17 and 88.9% of clay respectively as presented in Table 1 and MS has 25% of fine. According to Montgomery (2002), more cement is needed to counter the effect of high fines contents that result to high expansion. Therefore, sand was used to stabilize the clayed soil instead of using more cement. For black cotton soil and red coffee soil, the percentages (60%, 63% and 65%) of sand were added and the respective optimum moisture content and dry density were recorded, while on murram soil on the other hand, 20%, 50% and 60% of sand were added. Figures 2 to 4 show that with addition of 63% sand on black cotton soil and red coffee soil increased the optimum dry density from 1283.63 kg/m^3 to 1637.03 kg/m^3 and from 1327.33 kg/m^3 to 1696.14 kg/m^3 respectively while the addition of 60% of sand on murram soil increased the dry density from 1607.01 kg/m^3 to 1690.39 kg/m^3. Moreover there is corresponding reduction optimum moisture content from 25 to 15% on stabilized Black Cotton Soils (BCS) and Red Coffee Soils (RCS) however the reduction was minimal in the case of Marrum Soil (MS).

Effect of Sand on Black Cotton Soil, Red Soil and Murram Soil

Table 4 shows respectively the type of mixture, the number of crack and amount of shrinkage on patterns and from the table, Black cotton soil and red coffee soil without any type of stabilizer showed many cracks in addition to the shrinkage while murram soil did not present any crack but shrinkage. Addition of sand reduces the number of crack and amount of shrinkage considerably. With further addition of cement we observed neither crack nor shrinkage. The important remark here is that there are not cracks on black cotton soil with addition of 63% of sand. Due to the high content of expansive clay, black cotton soil has not yet been used as construction material. Figure 5 shows different type of blocks made with black cotton soil; it is revealed that black cotton soil

Table 3: Astm Soil Classification

Pebbles	Gravel	Sand	Silt	Clays
200 to 20 mm	20 to 2 mm	2 to 0.06 mm	0.06 to 0.002 mm	0.002 to 0 mm

Figure 2: Effect Of Sand On Optimum Dry Density and Optimum Moisture Content Of Black Cotton Soil

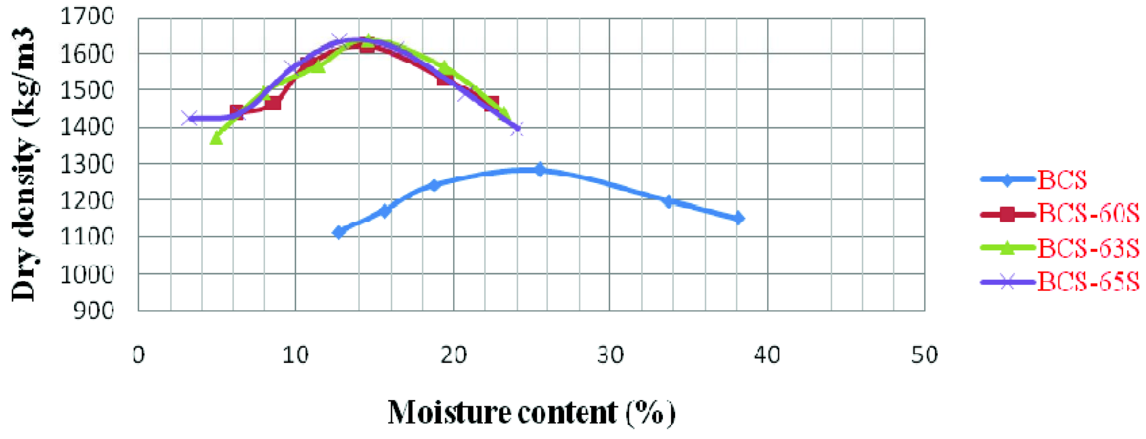


Figure 3: Effect of Sand on Optimum Dry Density and Optimum Moisture Content of Red Coffee Soil

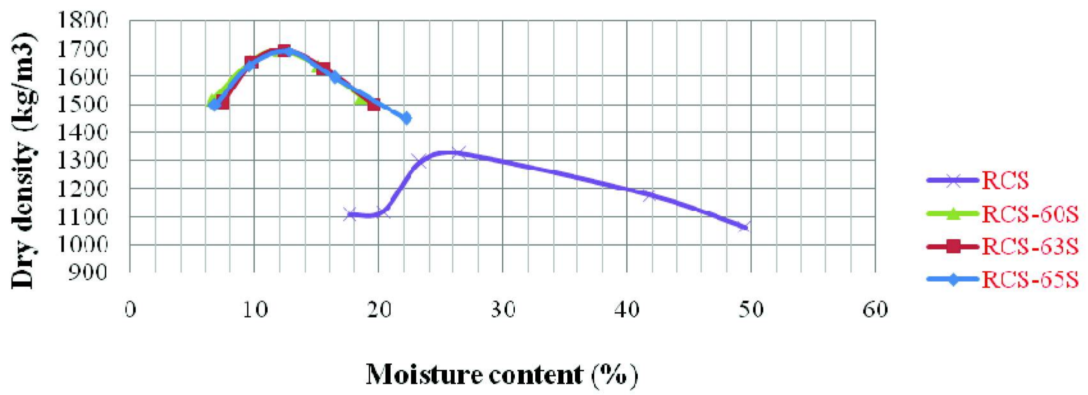


Figure 4: Effect of Sand on Optimum Dry Density and Optimum Moisture Content of Murram Soil

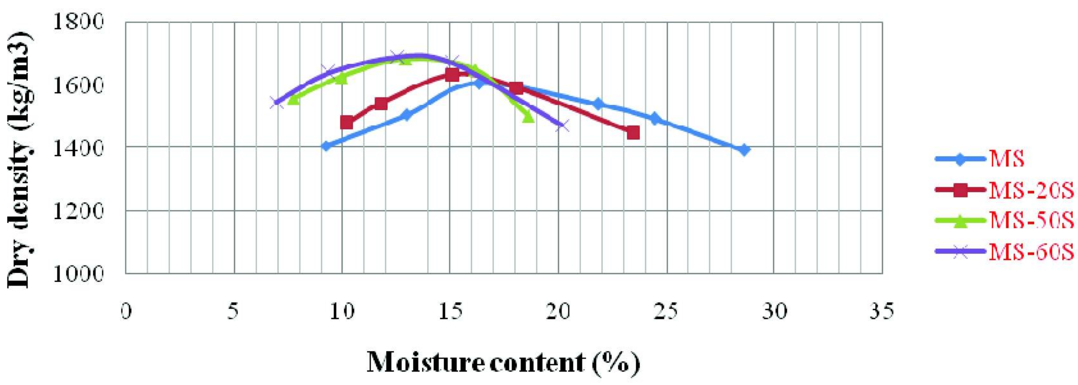


Table 4: Table representative of number of Crack and Amount of Shrinkage on Blocks

Blocks Label	Number of Cracks of Large Width	Linear Shrinkage Ls (mm)	Shrinkage Pattern
Red coffee soil			
RCS	5	30	
RCS-63S	3	8	
RCS-63S-6C	0	0	
Black cotton soil			
BCS	3	33	
BCS-63S	0	12	
BCS-63S-6C	0	0	
Murram soil			
MS	0	12	
MS-20S	0	8	
MS-20S-6C	0	0	

without any stabilizer resisted only for 7 days while with addition of sand and further cement/ lime, blocks resisted for 28 days.

Testing on Blocks

Dry compressive strength and water absorption tests were conducted on blocks. The minimum physical characteristics of cement stabilized soil blocks necessary for good construction per Kenya standard (KS-02-107:1993) are in Table 5.

Compressive Strength Test

The dry compressive strength was determined at ages of 7, 14, and 28 days using the Universal Testing Machine (UTM).

Table 5: physical Characteristics of Cement Stabilized Soil Blocks	
Physical Characteristics	**Minimum Values**
Dry Compressive Strength at 28 days	2.5 N/mm^2
Water absorption of blocks	15% of original dry mass
Shrinkage cracks	0.5 wide and < 50% of the parallel block dimension

Compressive strength result for each mixture was determined as an average of three sample blocks for each of the ages.

Effect of sand and chemical admixture on black cotton soil, red coffee soil and murram soil: Figures 6 and 7 describe respectively the effect of sand on black cotton soil, red coffee soil at 28 days. With addition of 63% of sand on black cotton soil and red coffee soil, the compressive strength increase respectively from 0.6 MPa to 1.9 MPa and from 2.8 MPa to 3.3 MPa. On addition of 6% cement the strength attained 3.01 MPa and 3.9 MPa for both black cotton soil and red coffee soil respectively. Figure 8 represented the effect of sand on murram soil at 28 days. The addition of sand increases the strength from 2.9 MPa to 3.4 MPa. With addition of 6% cement, the strength reached 4.4 MPa. Despite of the high quantity of sand added in red coffee soil and black cotton soil with addition to the cost of sand, this material seem to do not be economical. However, it can be still used if high strength is required since the use of sand reduce the amount of cement.

Effect of Hand Compaction on Compressive Strength: The aim of hand compaction was to compare the strength of blocks produced using only the compressive machine and those produced using hand compaction on 2 first layers and compressive machine on third layer. For this reason the mixture were: blocks with cement and sand (BCS-63S-6C, RCS-63S-6C, MS-20S-6C); blocks with sand, lime and cement (BCS-63S-4L-2C, RCS-63S-4L-2C, MS-20S-4L-2C) and blocks with only cement and lime (BC-4L-2C, RCS-4L-2C, MS-4L-2C). From Figure 9, it is shows that when the two first layers are compacted using hand, the compressive strength increases from 3.01 MPa to 4.3 Mpa for black cotton soil, from 3.9 MPa to 5.2 MPa for red coffee soil and from 4.4 MPa to 6.2 Mpa for murram soil when 6% of cement is added. Besides, it is observed that hand compaction increase strength in order of 1.5 MPa, 1 MPa and 0.5 MPa, respectively for mixture (BCS-63S-6C, RCS-63S-6C), MS-20S-6C, (BCS-63S-4L-2C, RCS-63S-4L-2C, MS-20S-4L-2C) and (BC-4L-2C, RCS-4L-2C, MS-4L-2C).

Water Absorption Test

Water absorption of blocks is one of the indicators that can be used to determine its durability (Ejem *et al.,* 2014, p. 16). Table 6 shows that only blocks with 6% of cement content resisted to water for 24 h for red coffee and black cotton soil which is not the case for murram soil where block resisted to water except block non stabilized. This result revealed that water absorption capacity of blocks reduces with type of soil and type of

Figure 5: Photograph of Different Blocks at Testing Ages

Figure 6: Effect of Sand and Admixture on Compressive Strength of Black Cotton Soil

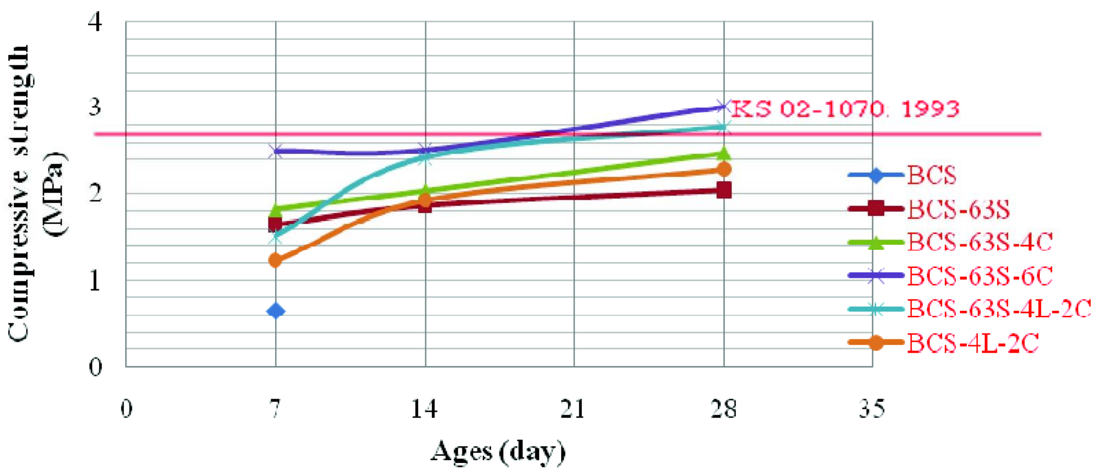


Figure 7: Effect of Sand and Admixture on Compressive Strength of Red Coffee Soil

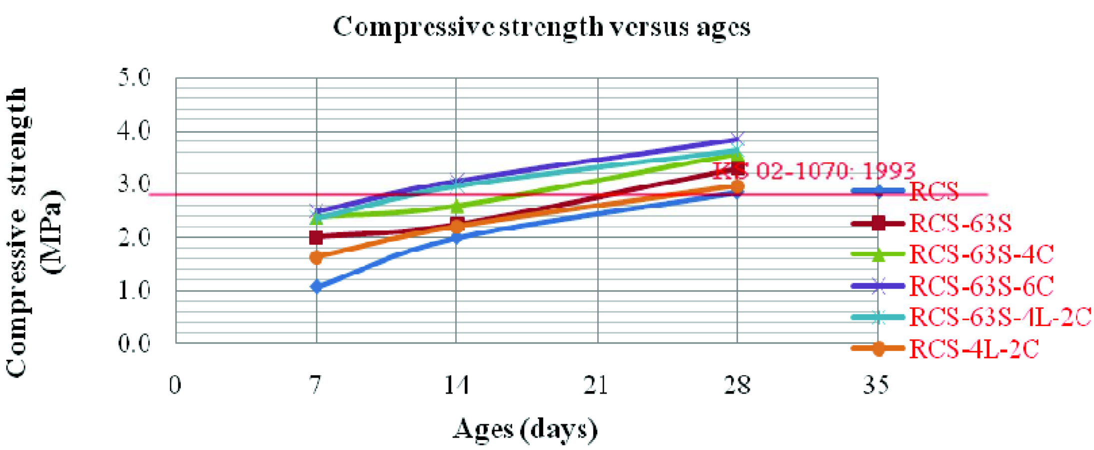


Figure 8: Effect of Sand and Admixture on Compressive Strength of Murram Soil

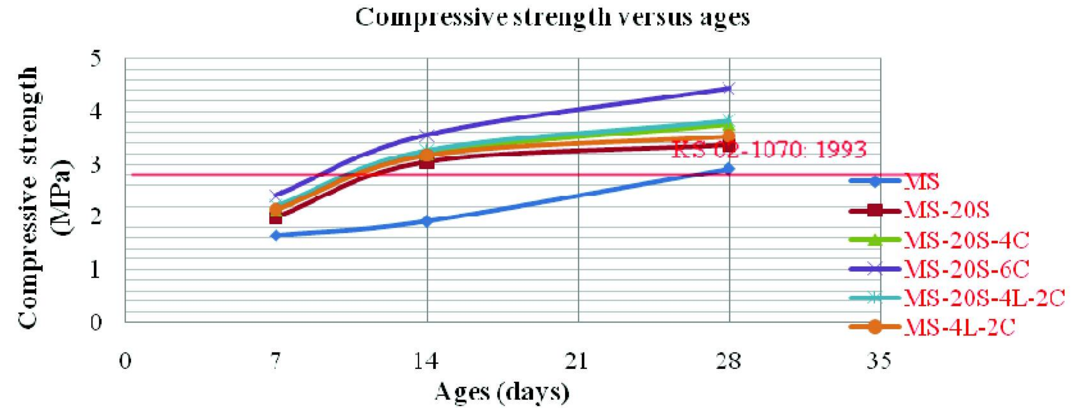


Figure 9: Effect Of Hand Compaction On Compressive Strength Black Cotton, Red Coffee And Murram Soil At 28 Days

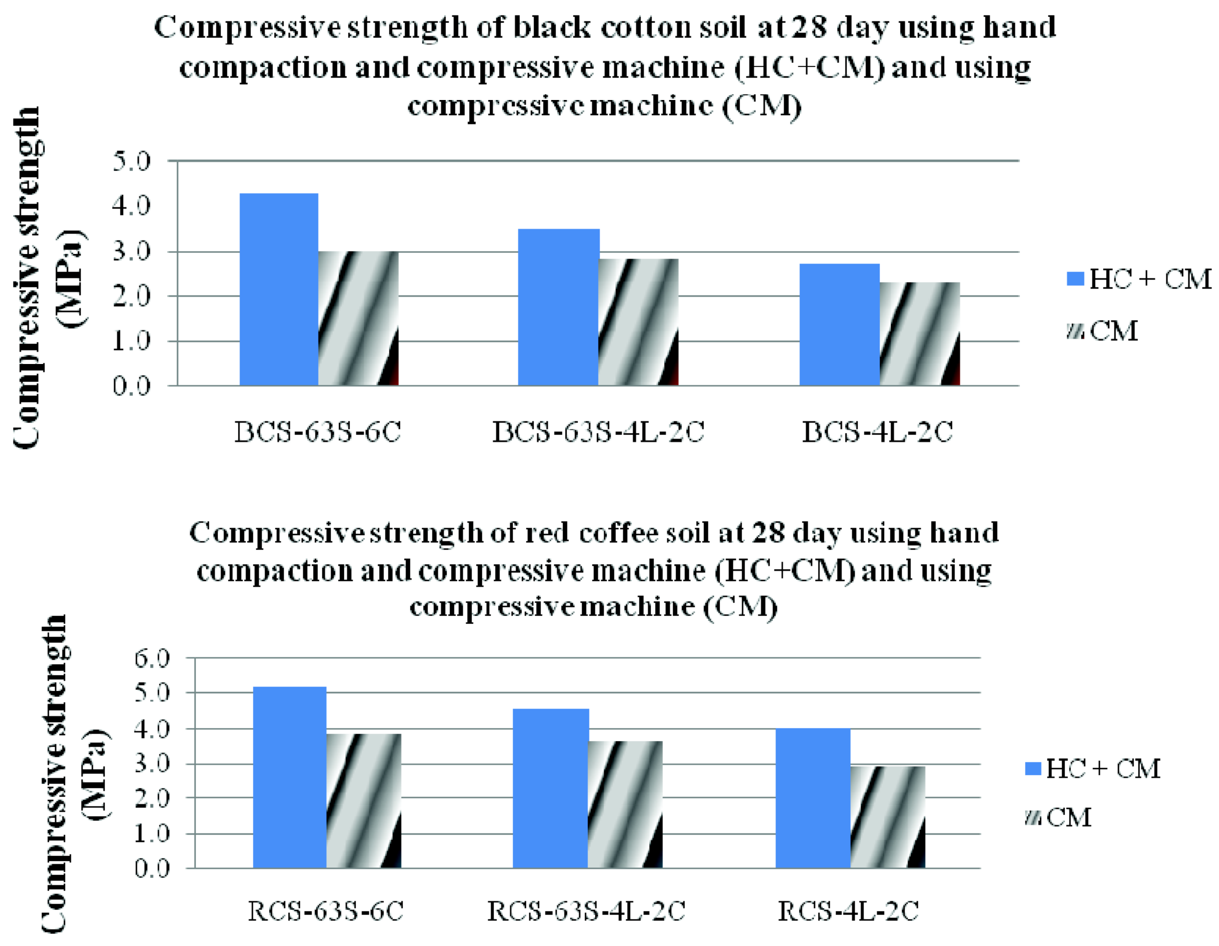
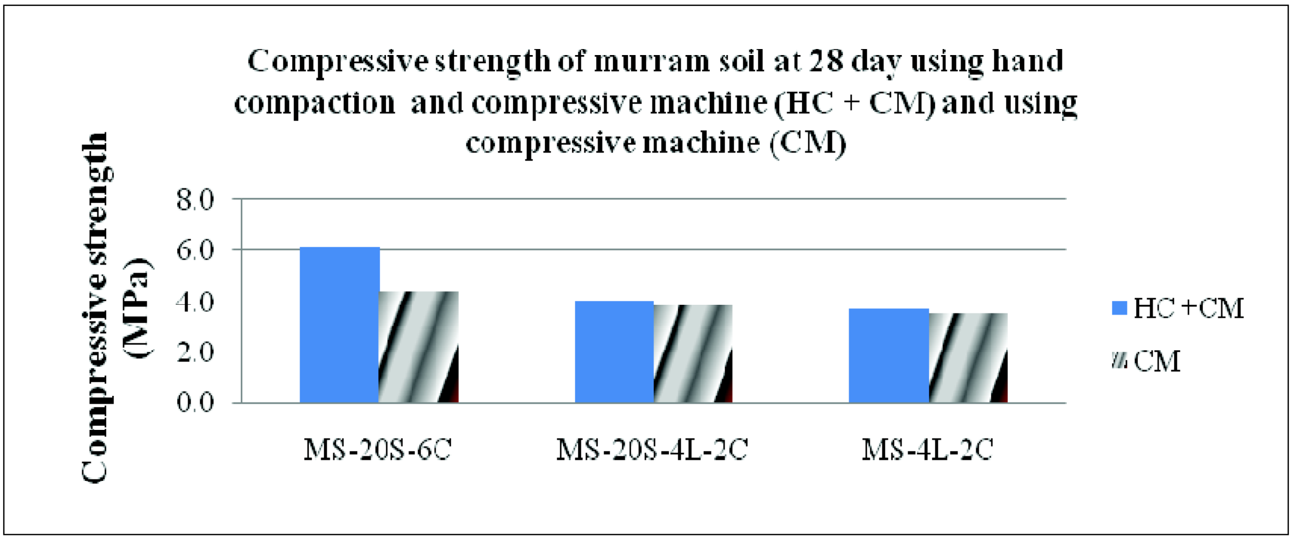


Figure 9 (Cont.)



stabilizer. Table 6 and Figure 10 presented the water absorption capacity of different types of blocks selected for the test. From Table 7, it is revealed that blocks produced using hand compaction on the first two layers and compressive machine are more compact than

Table 6: Water Absorption Test Results of Blocks Produced Using Compressed Machine

Blocks Label	Mass (G) Before Absorption Test	Mass (G) After Absorption Test (24h)	Change in Mass (G)	Water Absorption Capacity (%)
BCS		No sample representative		
BCS-63S-6C	8138.967	8828.25	689.2833	8.468929
BCS-20QD-6C	7072.95	Blocks fail before 24 h		
BCS-63S-4L-2C	9021.66			
BCS-4L-2C	6708.033			
RCS	6874.17			
RCS-63S-6C	8276.6	8921.633	645.0333	7.793458
RCS-20QD-6C	6959.567	Blocks fail before 24 h		
RCS-63S-4L-2C	8776			
RCS-4L-2C	6623.667			
MS	8217			
MS-20S-6C	8370	9128.45	758.45	9.061529
MS-20S-4L-2C	8558.5	9395.7	837.2	9.782088
MS-4L-2C	7720.75	8554.35	833.6	10.79688

Figure 10: Water Absorption Capacity for Block Produce Using Compressive Machine Only

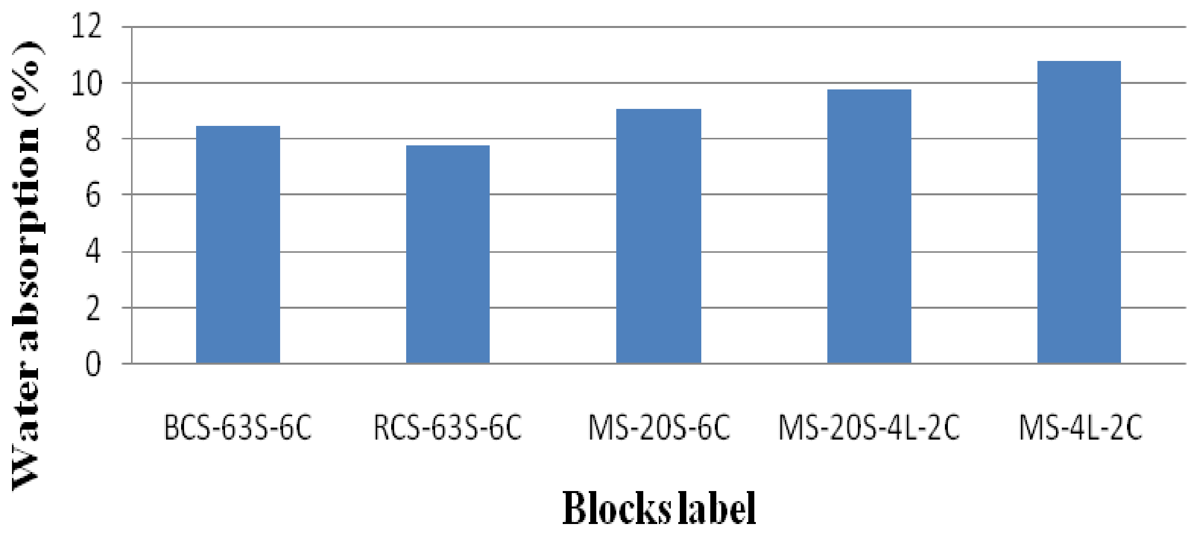
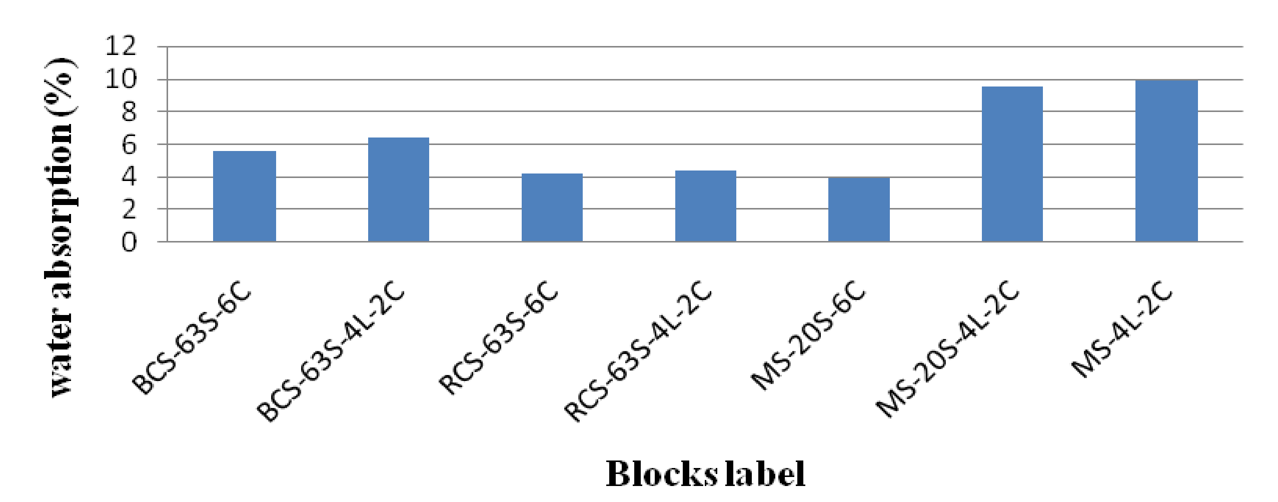


Table 7: Water Absorption Test Results of Blocks Produce Using Hand Compaction on The First Two Layers and Compressive Machine on the Third Layer

Blocks Label	Mass Before Absorption Test	Mass After Absorption Test	Change in Mass	Water Absorption Capacity
BCS-63S-6C	8889	9383.9	494.9	5.567555
BCS-63S-4L-2C	8304.7	8833.8	529.1	6.371091
BCS-4L-2C	7771	Blocks fail before 24 h		
RCS-63S-6C	8902.8	9276.1	373.3	4.193063
RCS-63S-4L-2C	8996	9389.5	393.5	4.374166
RCS-4L-2C	8425.2	Blocks fail before 24 h		
MS-20S-6C	9054.7	9415.1	360.4	3.980253
MS-20S-4L-2C	8396.6	9198.3	801.7	9.547912
MS-4L-2C	8282.2	9102.6	820.4	9.905581

those produce using only compressive machine and hence, absorb less water as compared to those which are produce using compressive machine only. Besides, the percentage of water absorption reduces from 8.47% to 5.58% for BCS-63S-6C, from 7.79% to 4.19% for RCS-63S-6C and from 9.06% to 3.98% for MS-20S-6C.

Figure 11: Effect of Hand Compaction on Water Absorption Capacity



CONCLUSION

The key objective of this research study was to determine the effect of hand compaction on the structural performance of black cotton soils, red coffee soil and murram soil in Kenya. Results obtained, demonstrate that the pressure used to produce block has an important effect on the compressive strength and durability of block. Indeed, it is determine that:

a) The strength of blocks increase with increase percentage of cement added.

b) Blocks produced using 2 layers hand compaction and compressive machine on the third layer are durable than those produced only by the use of compressive machine: the compressive strength increase from 4 to 6 MPa for murram soil stabilised, from 3 to 5 MPa for red coffee soil stabilised and from 3 to 4 MPa for black cotton soil stabilised blocks. While water absorption decrease from 6.05% to 0.9% for RCS-63S-6C, 3.15% to 0.8% for MS-20S-6C and from 7.4% to 2.4% for BCS-63S-6C.

c) The dry density increase from 1283.63 kg/m^3 to 1637.03 kg/m^{3}and from 1327.33 kg/m^3 to 1696.14 kg/m^3 when added 63% of sand on black cotton and red coffee soil.

d) Compressive strength depends on both type of soil and the pressure used for blocks compression. As the block is dense, the compressive strength increases while the water absorption capacity decrease and hence make the block durable.

e) The used of compressed stabilized earth blocks save 30% to 40% of the total cost of materials respectively for alternative block type 1 and type 2.

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