

# Durability of Compressed Stabilized Earth Blocks with Reduced Clay and Silt

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**Abstract.** Compressed Stabilized Earth Blocks (CSEB) has been using as a walling material since few decades. It is an environmentally friendly material but not economical in commercial application. Durability of CSEB is still under research and acceptance of CSEB by people also is a main challenge. Main ingredient that acts both positively and negatively on properties of CSEB is the presence of clay & silt. Many researches have been carried out on CSEB altering the clay content by adding sand, fly ash or similar materials. This study was carried out with the objective of establishing the feasibility of lowering clay & silt content by washing thus achieving requirements. The past research work established the optimum clay & silt in the region of 5 to 20% related to compressive strength but no firm indication of the range associated with the durability of CSEB. The test results based on a pilot study proved dry density is high with lower clay & silt below 15%. Water absorption test recorded that the water absorption is minimum between 10 to 15% of clay & silt content. The compressive strength did not show a significant drop or increase in the clay & silt range of 5% to 20%. These results conclude that the best range for clay & silt as 5% to 20% and can be best achieved by washing soils rather than mixing with sand, fly ash or any other similar material.

## 1. Introduction

Many research has been carried out related to Compressed Stabilized Earth Blocks, but its usage as a common building material is not as expected. The two main challenges of Compressed Stabilised Earth Blocks (CSEB) are related to durability and compressive strength. Guettala et al. (1) say moisture weakens CSEB reducing the strength of blocks. Walker (2) reported that due to the higher clay & silt content coupled with the lower cement content found in the CSEB when compared to ordinary concrete masonry units, as much as half the dry strength of CSEB can be lost when CSEB become saturated

It remains as an environmentally friendly material but not economical in commercial applications in many countries. The main variable for both of these critical parameters related to the amount of clay & silt in CSEB. As per Jayasinghe and Perera (3) there is an urgent need to develop economical and environmentally friendly alternative building material and CSEB is one such alternative material. Most of the past researches [ (1), (2), (3)] have focused on adding different soils, sand, fly ash, quarry dust, and other similar materials to alter clay & silt content. The addition of materials to alter clay & silt content improved the compressive strength but did not improve the durability in a significant way. Further, many failures reported in Sri Lanka, and other countries mainly related to the durability aspects of CSEB. The past research work related established the optimum clay & silt in the region of 5 to 20% related to compressive strength [ (2), (3)] but no firm indication of the range associated with the durability of CSEB. The lateritic soil is used for the production of CSEB and the content of clay &



silt in lateritic soils is generally around 20 to 35% range. This research examined the reduction of clay & silt content for production of CSEB and its relationship to compressive strength and durability.

With this background, the objectives of this paper are to review the available literature of CSEB, experimental investigation of soil block properties for reduced clay & silt using washing methods and to propose a recycling process for the wastewater produced with the soil washing process.

## 2. Research Methodology

The research was carried out by performing a literature review on compressive strength and durability of CSEB and experimental based results of properties of CSEB with reduced clay & silt of soils using washing methods.

## 3. Compressed Stabilized Earth Blocks

There are three standards related to Compressed Stabilised Earth Blocks published by Sri Lanka Standard Institution (4), (5), (6). There are different methods of producing building walls using soils and the main methods in Sri Lanka are CSEB, Wattle and daub, Rammed Earth Walls, and Cob or in the recent past introduced as Mud Blocks (7).

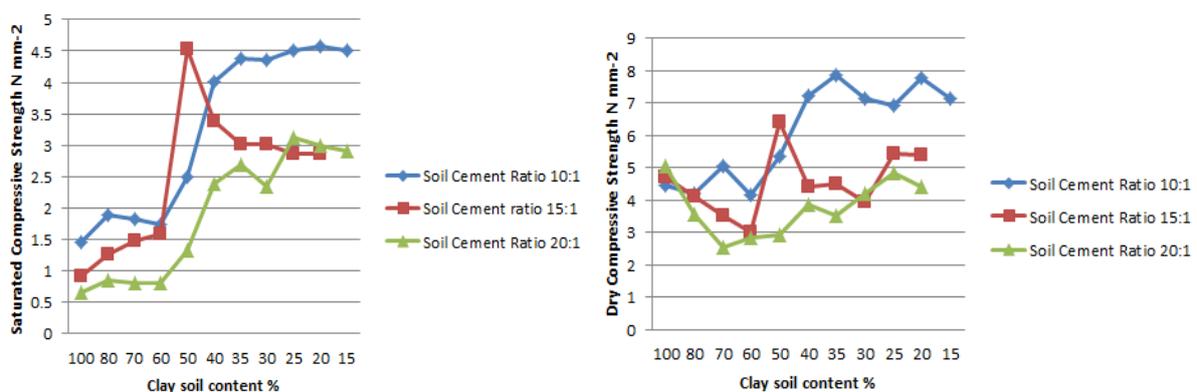
Compared to major masonry units like burnt bricks, cement blocks, etc., CSEB has considerable advantages related to the environmental effects. Haris (8) has clearly explained it as a less energy consumed and recyclable material. Jayasinghe et al. (9) explained the advantages of using CSEB for developing countries, as it does not need plastering since it has the finish same as wire cut bricks hence significant saving in cost. In addition, rural communities can involve to block making process using their spare time thus reducing the labour cost.

### 3.1. Clay and Silt Content for CSEB

The compressive strength and clay & silt content are well-researched variables for CSEB and often coupled with cement content. As Morel et al. (10) mentioned, the compression strength of the masonry units directly influences to the compression capacity of the masonry structure.

The Sri Lanka Standard for CSEB and many other literatures have defined the required range for clay as 10% to 15% and silt 5% to 20% (4), (11). Based on a comprehensive research work in India, Jagadish et al. have defined desirable clay range as 10% of 15% (12).

Also, Walker (2) has emphasized compressive strength has become a fundamental and universally accepted unit of measurement to specify the quality of masonry units. Figure 1 presents compressive strengths and clay content based on work presented by Walker (2) where similar results have reported by other authors.



**Figure 1:** Relationship of Saturated and Dry Compressive Strength and Clay Content (2)

Based on the test results by Walker (2), compressive strength has an increasing tendency for a lesser value of clay content. Also, as expected, compressive strength is high for high cement content. However, Walker has used clay content limited to 15% and by many of other researchers. Similar

results have been shown by Jayasinghe et al. (9) and Perera & Jayasinghe (13). Based on their experiments, compressive strength has an increasing tendency with decreasing fine content for different amount of cement.

Danso et al. (14) have investigated mechanical properties of soil block with fiber reinforcement for two different soil types. Both soils have more than 40% clay and silt content. It has shown, for these selected soil type, maximum compressive achievement is limited to 3 N mm<sup>-2</sup> even with fiber reinforcement.

### 3.2. Durability of CSEB

Many researchers have studied the effect of clay & silt for compressive strength, but limited studies have been carried out on durability. As per McGregor et al. (15), water absorption is clearly explained regarding different stabilization methods. Danso et al. (14) have also tested on wearing resistant and erosion only for high clay & silt contents. Therefore, it is important to re-visit the aspects of clay & silt, and the roles played to make blocks and its compressive strength. The best explanation of effects of clay & silt in CSEB is given by Rigassi (11). Other than the main characteristics such as dry and wet compressive strength, thermal insulation, apparent density, and durability are other main components to be investigated as suggested by Rigassi (11).

The decay of physical properties of conventional building mainly depends on the durability of the masonry units used. Therefore, properties such as fire resistance, weather ability, and effect of other accidental and environmental factors are the important properties to be tested. As per ASTM Test (16), durability was generally satisfied by 10% and 6-7% cement content except for those with very high clay content. Walker (2) also has proved this with wire brush test and drying shrinkage test. The durability of CSEB below 15% of clay & silt content has not tested by Walker or any other researcher.

Silt is made of particles of sizes varying from 0.002 and 0.06mm and not cohesive, do not play a significant role in bonding the particles of CSEB. However, in the presence of water, it displays cohesive properties but when moisture changes swell and shrink (11). The swell and shrink is not a good parameter for durability of CSEB. Gravels and sands also exhibit this property and the presence of silt in CSEB makes a difference compared to cement: sand blocks. However, silt fills the voids created by gravel and sand in CSEB, thus increases the density. The net result is the increase of compressive strength in the presence of cement as the bonding agent.

Clay, where particles sizes are less than 0.002mm, behaves quite different to silt, sand and gravel and has the characteristics of cohesiveness. Cohesiveness is mainly due to that clay particles are coated with thin layer of water and presence of high tension forces. This thin layer of water around clay particles forms a bond of all clay particles encompass sand and gravel and the main reason of the compressive strength of soil related construction. Compared to sand and gravel, clay displays instability for varying humidity. The high humidity makes clay absorb more water to the thin layer of water thus lose the compressive strength after the optimum moisture content. On the other hand however humidity to make the loose water in the thin water layer around clay thus causing shrinkage and cracks in soils related products. These cracks allow water to penetrate later as well as loss of the compressive strength. The presence of cement in CSEB will make a barrier for this moisture movement thus preserving the compressive strength and durability.

### 3.3. Sand and Gravel content for CSEB

The particle size of sand is 0.06 to 2mm and is a stable material in soils. In dry status, sand exhibits a significant mechanical internal friction. However, in the presence of moisture, it has good cohesion property due to the surface tension of water in voids of sand. Sand cohesion property facilitates cement: sand block manufacturing to retain the shape of blocks in the casting process.

The particle size of gravel is 2 to 20mm. Gravel is stable material in soils, and its properties do not get altered in the presence of water. The published research related to CSEB has little or no focus on varying the content of sand, gravel or sand and gravel. Most researchers either have assumed that there are no effects on parameters they have studied such as compressive strength or durability. The Sri Lanka standard for CSEB has put only a minimum limit of 65% for sand and gravel (4). The limit on sand and gravel is to control the content of clay and silt rather than sand and gravel.

### 3.4. Water Content of CSEB

Sri Lanka standards do not specify a limit for water for the manufacture of CSEB while controlling method is the drop test. The drop test very approximately guides to maintain the water content to the optimum moisture content while in liquid limit test it can be established more scientifically.

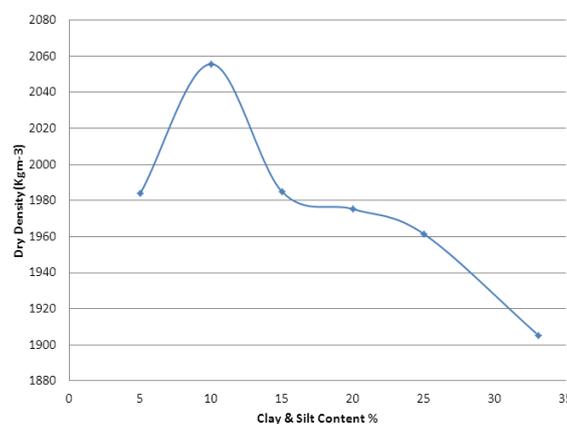
The quality of water is another important factor. It should be free from dissolved contaminants, suspended particles, and it should be fit for drinking water (17). Various researchers perform various tests on water like pH test, Hardness test, Chloride test, etc.

## 4. Discussion-Experimental Based Data

Most of the past research has been focused on clay & silt content limiting to a minimum of 15%. This study focused on the effect of lower clay & silt content for physical properties of CSEB for 6% of cement content. The experiment is a pilot study which will be expanded in future to make the results more strengthen. Main physical properties of CSEB like dry density, initial water absorption, and compressive strength were tested. Additionally, experiment setup was formed to check the feasibility of wastewater recycling process during soil washing with Potassium aluminum sulphate  $KAl(SO_4)_2$  or simply Potassium Alum. Optimum dosage of Potassium Alum and corresponding settling time for optimum Potassium Alum dosage was determined. All the test was carried out by following the standard procedures for testing.

### 4.1. Dry Density Test

Dry density was performed as per SLS 1382 Part 2 (Clause 5.3) [18]. Representative samples from six different clay & silt content were considered for the experiment. Figure 2 gives the average dry density obtained from the experiment. According to this investigation for reduced clay & silt, maximum dry density was given when the clay & silt content is 10%. Dry density for standard clay bricks is between 1800 to 2000  $kg\ m^{-3}$ . All these densities obtained through the experiment are in between this range while high-density values are correspondent to low clay & silt content.

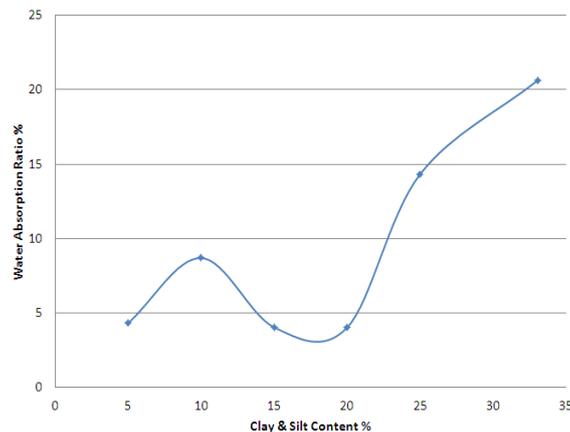


**Figure 2:** Experimental Relationship of Dry Densities with Reduced Clay & Silt

### 4.2. Water Absorption Test

The test was performed as per SLS 1382 Part 2 (Clause 5.4) (18). Water absorption is a key parameter to forecast on the durability of the soil cement blocks. If the water absorption is high, it can be expected a rapid deterioration of the soil cement blocks. The amount of the water absorption depends on the type of soil used and is related to the compressive strength and durability of the soil cement blocks. The durability of brick is mainly affected by the water absorption. This kind of unburnt blocks in the wet area require an insulation for the wall from rain infiltration because the biggest problem in the unburnt blocks is the water effect on the block strength. Experimental test results for water absorption corresponding to different clay & silt content is shown in Figure 3. Minimum water

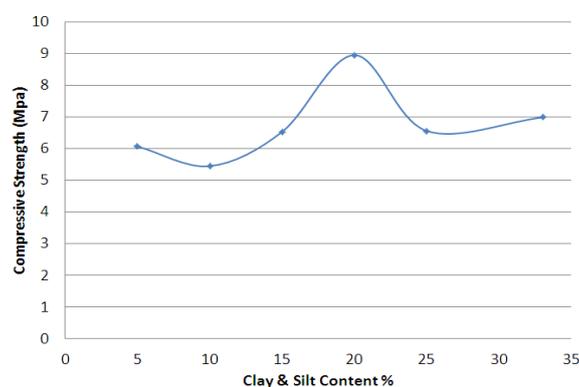
absorption can be seen when the clay & silt percentage is between 15 and 20%. Limitation value of 15 % for water absorption is mentioned in SLS 1382 (18). The block with the percentage of 33.08% clay & silt exceeds 15% limit of water absorption thereby the block is not suitable. However, the other percentages do not exceed the limit value and hence they are suitable.



**Figure 3:** Water Absorption for Reduced Clay & Silt Content

#### 4.3. Compressive Strength Tests

Compressive strength is the most researched and important parameter of soil blocks. According to SLS 1382 (18), the recommended 28 days dry compressive strength for the grade 1 soil cement blocks is 6MPa or above. Past research has shown dry compressive strength has an increasing tendency with decreasing clay & silt content. This research focused on this further reducing the clay & silt content. Figure 4 shows the relationship between the compressive strength and reduced clay & silt content. Except for one block, all other have achieved higher values than recommended value. The maximum value of 8.95 MPa recorded for the soil cement block with 20% clay & silt. Block with 10% clay & silt recorded the lowest value of 5.54 MPa. But according to the specifications given in SLS 1382, 5.54 MPa value falls between 4 MPa and 6 MPa and it can be categorized as grade 2 blocks (18).



**Figure 4:** Relationship between Compressive Strength and Reduced Clay & Silt Content

#### 4.4. Turbidity Test

As explained in above sections, most of the researchers have shown high clay & silt content is not suitable for CSEB production. Therefore clay composition should be lowered by removing the clay or

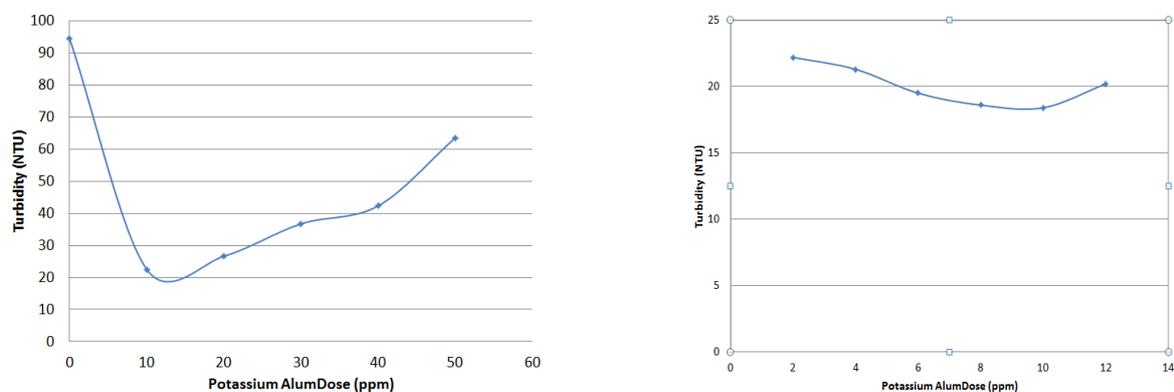
by adding sand to reconstitute the soil. In local context for small-scale manufacturers, clay removing would be more preferable if sufficient water is available. Also, if the washed water can be reused it can be more economical. Therefore, testing was carried out focusing on this aspect.

This practice covers a general procedure for the evaluation of treatment to reduce dissolved, suspended, colloidal, and non-settle able matter from water by Potassium Alum chemical coagulation-flocculation, followed by gravity settling and this was performed as per ASTM D2035 (19). The Potassium Alum solution prepared by mixing 1.0 grams of Potassium Alum with 1000ml of distilled water to make a 0.1% strength solution.

Sand is an essential raw material for civil engineering construction purposes. The traditional method was to obtain sand directly from river beds. That led to the erosion of the river bed. Furthermore, surrounding area was affected by loss to the environment and even led to floods. When people understood the situation to avoid this disaster, they began to go in search an alternative. One of the alternatives was to use sea sand. But there were hazards in using sea sand because it contains ions from various compounds that may cause to decrease the quality of sand related products. Since sea sand content less coarse particles the strength of products made from sea sand is not sufficient for civil engineering construction purposes. The removal of ionic particles is a complicated process which cost unnecessarily. Considering all these factors, direct use of soil is an alternative method. Soil will have to be first washed to extract the sand. The washed-out water if allowed to drain off; it will affect the environment. So, the drained away water should be recycled. The larger particles will naturally precipitate as sediment. Potassium Alum could be used to accelerate the remaining finer particles.

One of the objectives of the research was to determine the optimum amount of Potassium Alum that should be used to get this sedimentation. An experiment was done to obtain this value by collecting the washed away water in a 3ft height barrel. 200mm of high of water collected from top water level to carry out the jar test.

Turbidity measurement in the first trial for different Alum dosages used for washout water is shown in Figure 5.



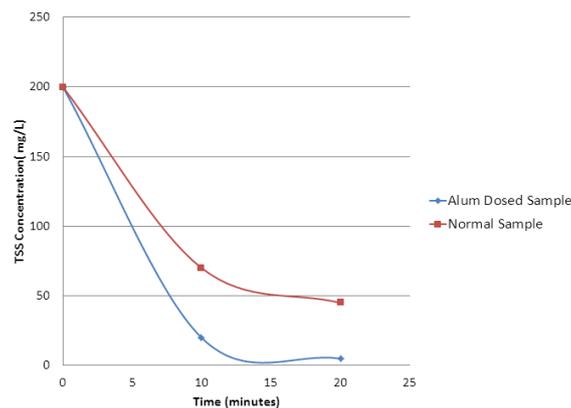
**Figure 5:** Turbidity Variation for Different Alum Dosages-Trial 1 and Trail 2

According to Figure 9, the optimum value obtained between 10ppm and 20ppm closer to 10ppm. Another trial was made using similar conditions to find out the exact value. Amounts were varied as from either side of 10ppm, and the results are shown in Figure 10. Concerning the above graph, the value of 10ppm of Potassium Alum dosage was confirmed as the optimum value that can be used for sedimentation.

#### 4.5. Determination of Settlement

Settling time of the total suspended solids of optimum Potassium Alum dosed washed water was determined by performing TSS Concentration Test.

There are various soil washing plants which contribute to obtaining pure sand. But their lack of awareness of the scientific procedure for water recycling has led to delay in the production as well as causing adverse impacts on the environment and a higher expenditure production. To avoid these difficulties, tests were conducted to obtain the time taken for maximum sedimentation with the addition of Potassium Alum and without the use of Potassium Alum. Test results are shown in Figure 6.



**Figure 6:** TSS Concentration for Different Setting Times

It is evident that rapid drop with the addition of Potassium Alum than without Alum. It proves that for  $200 \text{ mg l}^{-1}$  of initial concentration the addition of Potassium Alum gives a better sedimentation when time duration is 20 minutes. It helps to resolve the issues mentioned above.

## 5. Conclusion

Compressed Stabilized Earth Blocks (CSEB) has been subjected as a key researched masonry unit during last few decades. Many researchers have concluded compressive strength is increasing with decreasing clay & silt content. But most of the researchers' focus is up to 15% of clay & silt content. Some researchers show high durability with reduced clay & silt content regarding drying shrinkage and wire brush test, yet the strong relationship was difficult to achieve.

A study conducted by lowering clay & silt content below 15% gave a similar trend. Experimental results showed 20% clay & silt content gave maximum compressive strength and compressive strength for lesser clay & silt is above the standard values. Similarly, tested CSEB has high dry density with reducing clay & silt below 15%. Highest dry density is recorded with 10% of clay & silt content. Water absorption test recorded between 10 to 15% of clay & silt content, water absorption is minimum. Further testing is required to strengthen these conclusions.

One of the main objectives of this experiment is to propose a recycling process for the wastewater produced with the soil washing process. Jar test results showed the optimum coagulant amount as 10ppm for initial total suspended solid concentration of  $200 \text{ mg l}^{-1}$  of washed water. Through the TSS concentration test, the time taken for complete sedimentation was found to be 20 minutes with the addition of the required amount of Potassium Alum. With this soil washing process, additional clay will be removed. This removed clay is very fine and in large-scale production, removed clay content will be significant. It can be used for some other purposes like tile making.

Usually, CSEB is produced with the soils available at specifically selected areas since it is necessary to control the clay & silt content. This research shows a path to remove the silt & clay from any soil for the purpose of making blocks with better strength and durability. So, this research helps to

introduce a low-cost alternative for CSEB production with minimal environmental impact for sustainable development in the construction industry.

## 6. References

- [1]. Guettala A, H.Houari , Mezghiche B, Chrbili R. *Durability of Lime Stabilized Earth Blocks*. Courier Du Savoir. 2002 June; No 2 pp 61-66.
- [2]. Walker PJ. *Strength, Durability and Shrinkage Characteristics of Cement Stabilised Soil Blocks*. Cement & Concrete Composites (17). pp. 301-310, 1995.
- [3]. Jayasinghe C, Perera AADAJ. *Stabilized Soil Block Technology for Sri Lanka*. Research for Industry, Engineering Research Unit; 1999; University of Moratuwa, Sri Lanka. p. 147-160.
- [4]. Sri Lanka Standard Institution. *SPECIFICATION FOR COMPRESSED STABILIZED EARTH BLOCKS : Part 1 Requirements* Colombo: Sri Lanka Standard Institution; 2010.
- [5]. Sri Lanka Standard Institution. *SPECIFICATION FOR COMPRESSED STABILIZED EARTH BLOCKS : Part 2 Test Methods* Colombo: Sri Lanka Standard Institution; 2010.
- [6]. Sri Lanka Standard Institution. *SPECIFICATION FOR COMPRESSED STABILIZED EARTH BLOCKS : Part 3 Guidelines on production, design and construction* Colombo: Sri Lanka Standard Institution; 2010.
- [7]. Udawatta C, Azoor R, Halwatura R. *Manufacturing framework and Cost optimization for Building Mud concrete Blocks (MCB)*. Science Council of Asia. ; Vol 10, p 112.
- [8]. Haris DJ. *A quantitative approach to the assessment of the environmental impact of building materials*. Building and Environment. vol.34, pp.751-758, 1999.
- [9]. Jayasinghe C, Perera AADAJ, West S. *The Application of Hand Moulded Stabilized Earth Blocks for Rural Houses in Sri Lanka*. In EARTHBUILD2005; 2005; University of Sydney. p. 178-187.
- [10]. Morel JC, Abalo P, Walker P. *Compressive strength testing of compressed earth blocks*. *Construction and Building Materials*. vol. 21, pp. 303-309, 2007.
- [11]. Rigassi V. *Compressed Earth Blocs: Manual of Production*: Eschborn: Deutsches Zentrum fur Entwicklungstechnologien - GATE; 1985.
- [12]. Jagadish KS, Reddy BVV, Rao KSN. *Alternative Building Materials and Technologies* New Delhi: New Age International (P) Limited; 2007.
- [13]. Perera A, Jayasinghe C. *Strength Characteristics and Structural Design Methods for Compressed Earth Block Walls*. Masonry International. 2003; Vo 16, pp 34-38: p. 34
- [14]. Danso H, Martinson DB, Ali M, Williams JB. *Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres*. *Construction and Building Materials*. vol. 101 pp. 797–809, 2015.
- [15]. Gregor FM, Heath A, Foddo E, Shea A. *Condition affecting the moisture buffering measurement performed on compressed earth blocks*. *Building and Environment*. vol. 75, pp. 11-18, 2014.
- [16]. ASTM. *Wetting and Drying Compacted Soil-Cement Mixtures*: American Society for Testing and Materials, Philadelphia; 1989.
- [17]. H.Patil S. *Research on Interlocking Stabilised Soil Bricks (I.S.S.B)* A Literature Survey. IJRE. Vol 05, Issue 03 pp375-378, 2016.
- [18]. Sri Lanka Standard Institution. *SPECIFICATION FOR CEMENT STABILIZED EARTH BLOCKS : Part 2* Colombo: Sri Lanka Standard Institution; 2009.
- [19]. ASTM D2035. *Coagulation Flocculation Jar Test of Water*: United States of America: ASTM; 2013.