Comparison of Strength Between Laterite Soil and Clay Compressed Stabilized Earth Bricks (CSEBs)

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Abstract. Compressed Stabilized Earth Brick (CSEB) is a sustainable material utilizing locally available soils mixed with stabilizers to increase its strength. Two main factors affecting the strength of prototype are its compressive strength and water absorption rate. In this study, the mix proportion ratio for producing CSEB prototypes from laterite soil and clay types was 1:10 (cement:soil). Three different compactions (i.e. 2000, 3000, and 4000 Psi) were applied to produce prototypes with dimension of 100×50×40 mm. The samples were tested at the ages of 7 and 28 days. For laterite soil CSEB, the optimum strength was achieved by the sample subjected to 2000 Psi compaction, with its compressive strength of 9.0 N/mm² and water absorption rate of 14.9%. For clay CSEB the optimum strength observed was the sample subjected to 4000 Psi compaction, with the compressive strength of 5.8 N/mm² and water absorption rate of 17%. However, the compressive strength of clay CSEB is still below the level specified in the MS 76:1972, which is over 7 N/mm² for the load-bearing fired brick Class (1). This study also revealed that the increased in compression pressure would result in different strength performances for both CSEBs made from laterite soil and clay.

1 Introduction

Until recently, more than half of the world's population have chosen to build their homes of this soil-based structures due to its high durability, low cost, good resistant to fire and weather factors, and aesthetically attractive [1- 5].

Compressed Stabilized Earth Brick (CSEB) is a green technology in building construction, which has been explored using locally available materials. Soil-based home construction has begun since 1950s in Bogota, Colombia, initially introduced by Raul Ramirez [6]. According to the UNESCO Chair Earthen Architecture [7], clay and laterite soil are suitable to be used in the production of CSEBs, and they are readily available in

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Malaysia [8]. From using manually controlled pressure in a steel mould in early 1950s, the process of producing CSEBs has undergone many changes. In recent years, hydraulic compression machine has been widely used to improve the quality and also to optimize the cost, effort and time in producing CSEBs [9].

Currently in Malaysia, there is no standard in producing CSEB made from laterite soil and clay. Therefore, this study aims at quantifying the compressive strength and water absorption rate of CSEBs made from laterite soil and clay. The values obtained can be used as references and standards in CSEB production in Malaysia.

2 Overview of CSEB prototype

Fig. 1 shows a CSEB prototype produced with dimensions of 100×50×40 mm. It resembles an Interlocking Compressed Stabilized Earth Brick (ICSEB) sized 100×125×250 mm in terms of strength, mixing ratio, and other attributes. The main purpose of producing this prototype brick is to test its compressive strength and water absorption rate.

Fig. 1. CSEB prototype dimension.

Soil is the main component for the production of CSEBs [10]. The other ingredients include Ordinary Portland Cement (OPC), sand and water. The properties of the soil and local climatic conditions in a given area should be determined prior to producing CSEB. For instance, dry climatic regions of African continent require different soil than that of tropical climates. Thus, not all types of soil can be used in producing CSEB. Generally soil containing some clay and mud is suitable as it facilitates the adhesion process. The best soil composition contains 15% gravel, 50% sand, 15% silt and 20% clay [10].

Laterite soil consists of clay and iron particles, and characterized by its hardening properties, chemical content and structural evolution. It is porous and soft at high humidity, where exposing it continuously to high ambient temperatures would cause it to harden [11]. In contrast, clay comprises small pores of air and solid particles with no void spaces. It is also soft at high humidity and will quickly harden if continuously exposed to high ambient temperatures. However, clay has a low shear strength and high compressibility level [11].

Sand is also known as the fine aggregates. For CSEB production, the sand should be reasonably fine (i.e. passing 2 mm sieve size) as well as clean and free from any organic material as required by the standard. Additional sand will only be required if the percentage of existing sand content is less than one-third of the overall soil quantity [12].

Cement is a good stabilizer in the production of CSEB since it has adhesive properties that bond minerals' particles together. In this study, OPC was chosen due to its suitability as admixture in the production of soil-based products. Moreover, this type of cement is also highly suitable for use in a variety of climatic conditions [13].

Water must be clean and free from impurities such as organic and sulphate. The presence of impurities will affect the hydration process particularly during the hardening

stage of the bricks. Whereas, during the curing stage, water is needed for a perfect hydration of cement. The amount of water needed in the mixture is between 10 - 20% [11].

3 Preparation of soil for CSEB

Laterite soil and clay were selected to be the main ingredients in the production of CSEB prototypes. Theywere taken at a depth of 1.5 m below ground surface, whereby laterite soil was obtained from a place in Ayer Hitam and clay was acquired from a place in Parit Raja.

The soil samples were analysed and compared with the results found by previous researchers. In particular, analysis results of laterite soil and clay samples were compared with those of Wahab [14] and C.M. Chan [15], respectively. Several tests, which include Particle Distribution Test, Atterberg Limits Test, Chemical Composition Test, and Jar Test, were carried out in accordance to BS 1377:Part 2:1990 [16].

3.1 Particle distribution test (sieve analysis)

Most of the mixing ratiosin producing CSEB prototypes consist of aggregated materials, namely soil and sand, which will particularly affect their durability and performance. Sieve test is crucial for obtaining the rate of aggregate mixture of various sizes.

Based on the AURAM Press 3000 [10], soil containing 15% gravel, 50% sand, 15% silt and 20% clay is considered as having the best soil composition for producing CSEB. Particle Distribution Test on laterite soil found that the percentage of aggregate mixtures of the soil composition were almost similar to those performed by Wahab [14], as outlined in Table 1. These percentages of the composition indicate the suitability of the soil to be used in producing CSEB. For clay, the test results showed that percentage of aggregate mixtures were almost similar to those obtained by C.M. Chan [15]. Apparently, clay composition did not match with that of the best soil composition required for producing CSEB.

Table 1. Soil particle size distribution.

Soil Type	Place taken from (Researcher)	Clay (%)	Sand (%)	Gravel (%)	Mud (%)
Laterite Soil	Ayer Hitam (Wahab,[14])	4	86	10	-
		7.4	71.5	21.1	-
Clay	Parit Raja (C.M.Chan, [15])	25.8	0.9	-	73.3
		10.23	0.57	-	89.2

3.2 Atterberg limits test

This experiment is carried out to identify and classify soils samples that have been dried, particularlyto determine the value of liquid limit (LL), plastic limit (PL) and the plasticity index (PI) of the soil samples. The determination of these limits is also used to predict the shear strength and soil sedimentation. Both laterite soil and clay samples had passed through 0.425 mm sieve.

The results of Atterberg limits test as outlined in Table 2 has proven that the laterite soil of Ayer Hitam and clay from Parit Raja to be used in the production of CSEB prototypes in this study are classified as laterite soil and clay. There are obvious similarities in terms of the values for liquid limit (LL), plastic limit (PL) and the plasticity index (PI) of the laterite soil from Ayer Hitam as investigated by Wahab [14], as well as clay from Parit Raja as examined by C.M. Chan [15].

Table 2. Atterberg limits.

Soil Type	Place taken from (Researcher)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)
Laterite Soil	Ayer Hitam (Wahab, 2008)	43.8	22.5	21.2
		45.0	23.1	21.9
Clay	Parit Raja (C.M.Chan, 2008)	67.5	32.04	35.5
		68	32	35

3.3 Chemical composition test

In order to run this test, samples of clean soil sized 63 µm in the form of dust / dry powder should be prepared. The results of chemical composition analysis, as summarized in Table 3, found that the content of Silicon Dioxide (SiO2) is the highest within the two types of soil samples, which is 42% for laterite soil and 60.6% for clay, respectively. This silica content can help in strengthening the compressive strength of the CSEB prototypes when reacting with cement due topozzolanic process. The high content of lime or Calcium Oxide (CaO) of about 53.6% in cement, would enhance its performance as binding agent between both soil and sand particles.

Table 3. Material chemical composition (weight percentage).

Types of Chemical	Laterite Soil (%)	Clay (%)	OPC (%)
Carbon dioxide, CO ₂	0.10	0.10	0.10
Iron (iii) oxide, Fe ₂ O ₃	19.00	6.39	5.10
Silicon dioxide, SiO ₂	42.00	60.60	23.40
Aluminium oxide, Al ₂ O ₃	35.00	22.40	10.60
Calcium oxide, CaO	0.29	0.00	53.60
Titanium dioxide, TiO ₂	1.01	0.92	0.97
Potassium oxide, K ₂ O	1.80	2.43	0.71
Sulphur trioxide, SO ₃	-	5.63	3.76
Sodium oxide, Na ₂ O	0.27	0.32	0.27
Magnesium oxide, MgO	0.21	0.88	1.15

3.4 Jar test (sedimentation test)

Soil is a complex building construction material where each soil sample is different from one to another. The Jar test was carried outto determine the composition and the ratio of soil particles. It was observed that the laterite soil samples obtained from Ayer Hitam contains 75% sand and 25% clay. In order to get a good distribution of the particles, the mixture ratio of CSEB prototype should be designed with 1:8:2 (cement:soil:sand). Hence, the existing soil should be added with additional sand as much as 25% of the amount used. Whereas, the clay samples taken from Parit Raja had approximately 15% sand and 85% mud and clay. Since the content of mud and clay is very high, the soil should be modified with mixture ratio of 1:5:5 (cement:soil:sand). This modification is done by adding large quantities of sand to form CSEB prototypes that can withstand compressive stress.

3.5 Raw materials density

The density of the raw materials used in the production of CSEB prototypes is determined in accordance to BS 1881:Part 114:1983 [17], and the results are summarized in Table 4.

Table 4. Density of raw materials.

Material	Density (kg/m ³)
Water	1000
Cement	1095
Laterite Soil	1286
Clay	1095
Sand	1524

3.6 Sampling and testing of CSEB prototype

Three different compactions (i.e. 2000, 3000 and 4000 Psi)were considered in the production of CSEB prototypes. As mentioned earlier, the mixture ratios of cement:soil:sand for both types of soil were 1:8:2 for laterite soil, and 1:5:5 for clay, respectively. The raw materials were mixed together manually based on the required mixture ratiosin producing CSEB prototypes with dimension of 100×50×40 mm. The percentage of water required to produce a good mixture is between 10 - 20% of the weight of the soils. While mixing, a small portion of this mixture was hand gripped to form a soil ball and then dropped to the ground at a height of one metre. The shape and condition of the fallen soil ball would determine the optimum water content needed. The optimum rate of water content is achieved when the fallen soil ball broke into 4 or 5 fractions on the ground. As a result, the optimum percentage of water required for the mixture was found to be 15% for laterite soil and 20% for clay, respectively.

The well-mixed mixture was poured into the mould, and then compacted using a hydraulic compaction machine at three different pressure values of 2000 Psi, 3000 Psi and 4000 Psi. Each prototype sample should be carefully taken out from the mould not to damage its shape at the early stage of production. Each sample should be labelled accordingly to the compaction applied, and subsequently placed in an open area. The curing process was done by spraying each of the prototype samples with water manually every day up to either 7 or 28 days.

CSEB prototype samples were tested for compressive strength and water absorption rate at the age of 7 and 28 days. Universal Testing Machine (UTM) was used for testing compressive strength. For water absorption test, which was based on BS EN 771:Part 1:2003 [18], the cooling method was employed where each prototype sample was weighed and dried in an oven for 24 hours at a temperature of 105 °C. The sample was then soaked in water for 24 hours at room temperature. The percentage rate of water absorption was determined by dividing the weight of the sample after immersion with the weight of dry sample, and then multiplied by 100%. Each physical testing of CSEB prototypes was carried out using 3 samples, and the average value of the samples would be considered accordingly as the final value for both compressive strength and water absorption rate.

4 Results and discussion

4.1 Compressive strength

The CSEB prototype samples produced with different compactions were physically tested through compressive stress test at the age of 7 and 28 days. It was observed that the quantity of laterite soil to be poured into the mould would increase accordingly to the compaction pressures applied. For 2000 Psi compaction, the amount of laterite soil required is 400g. Whereas, 427g and 450g of laterite soil were required for compactions of 3000 Psi and 4000 Psi, respectively.

From Fig. 2(a), it can be seen clearly that the compressive strength of laterite soil CSEB prototype is at its optimum when subjected to 2000 Psi compaction with the strength values increase from 9.0 N/mm² for sample age of 7 days to 14.8 N/mm² for 28 days old sample. However, as the prototype samples were subjected to compactions of 3000 Psi and 4000 Psi, their compressive strength at 28 days still achieved the predetermined level of strength as stated in MS 76:1972, load-bearing fired brick Class (1), which is at least 7 N/mm² [19]. In general, it can be inferred that for all values of compaction pressure applied, the compressive strength of laterite soil CSEB prototypes would be greatly influenced by the age of samples. The increasing age of the samples from 7 days to 28 days would also result in the increase of its compressive strength.

To produce clay CSEB samples, the quantity of clay required to be poured into the mould would increase accordingly to the compaction pressures applied. For 2000 Psi compaction, the amount of clay needed was 410g. Whereas, 437g and 462g of clay were required for compactions of 3000 Psi and 4000 Psi, respectively. Since clay has very high percentage of mud content as confirmed by the particle distribution test, it has to be modified by adding sand to the mixture to form a ratio of 1:5:5. It was also observed that laterite soil content is heavier than clay.

Fig. 2. Compressive strength (N/mm²) vs.Age of CSEB prototypes (7 and 28 days).

Fig. 2(b) shows the results of the compressive strength of clay CSEB prototype samples. It can be seen clearly that the increased in compaction pressure applied would result in higher compressive strength. The clay CSEB prototype subjected to compaction of 4000 Psi gave the optimum compressive strength value for 7 days sample. Surprisingly, the value of compressive strength lessened to 5.16 N/mm² as the age of the sample increased to 28 days. Generally, it can be presumed that for all values of compaction applied, the compressive strength would reduce with the increasing age of the prototype samples from 7 days to 28 days. Additionally, the compressive strength of clay CSEB prototype is generally below the predetermined level of strength as stated in MS 76:1972 for load-bearing fired brick Class (1), which is at least 7 N/mm² [19]. This is due to the fact that clay has a very high mud content; and therefore, could not bear the compressive stress imposed.

4.2 Water absorption rate

The results of water absorption rate test on CSEB prototype samples were compared with those of the load bearing fired brick Class (1) based on MS 76:1972 [19]. Although it is not specified in the standard with respect to water absorption rate, the Malaysian construction industry has commonly adopted the absorption rate of less than 15% for this type of brick. Lower absorption rate indicates better quality bricks and higher resistant to the adverse effects of weather.

Fig. 3(a) shows the results of the water absorption rate of laterite soil CSEB prototypes. It can be seen clearly from the graph that the increased in compaction would generally result in lower rates of water absorption. Furthermore, for all values of compaction applied, the quality of laterite soil CSEBs improves as their ages increased from 7 days to 28 days as evidenced by lower percentage rate of water absorption. The rate of water absorption is at its optimum when subjected to 4000 Psi compaction with percentage rates dropped down from 15.4% for sample age of 7 days to 14.5% for 28 days, respectively. This condition occurs due to the fact that higher compaction applied would make the samples become denser, which in turn preventing the absorption of water.

Fig. 3. Water absorption rate (%) vs.Age of CSEB prototypes (7 and 28 days).

Similarly for clay CSEB prototypes, increasing compaction pressures had resulted in lower water absorption rate as shown in Figure 3(b). Apparently, greater compaction applied means heavier compaction of mixture in the mould resulting in a denser sample that prevents the absorption of water. Thus, increasing the curing age of clay CSEBs would result in higher absorption rate. The optimum absorption rate for clay CSEBs was achieved by the sample subjected to 4000 Psi compaction with the values of 17.3% at the age of 7 days and 18.5% at 28 days, respectively. However, both values of absorption rate still exceed the allowable limit of 15%. The observation on physical properties found that the prototype will decompose at every vertices when touched by hand during the transportation process. It can be inferred that the pozzolanic reaction between aggregates within the content of this prototype is very weak.

5 Conclusion

It can be firmly concluded from experimental results that laterite soil is more suitable than clay for CSEB production. It is essential to ensure good distribution of particles during the mixing and compacting processes of producing CSEB. Well-mixed mixture of small and large aggregates can be achieved when the smaller ones filled up the empty spaces in between the larger aggregates. Therefore, mixture ratio of 1:8:2 (cement:soil:sand) was deemed suitable to produce laterite soil CSEBs with 2000 Psi compaction. At this optimum compaction, the aggregate mix remained in its original condition without changing its form. Moreover, all the results of the compressive strength (N/mm^2) and water absorption rate (%) are found to be in accordance with the standards as specified in MS 76:1972 [19].

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