Sustainable use of laterite soil as compressed cement stabilized earth block for low cost housing construction

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Abstract. Developing countries facing challenges in provision of housing especially with the increasing population in Malaysia, large demand on the construction materials resulting the construction cost to increase tremendously. Using low-cost housing material will be beneficial to provide affordable housing in order to meet society needs. This study investigates the sustainable use of laterite soil as a construction material for the production of compressed earth block stabilized with cement. Engineering properties of the laterite soil were determined using moisture content, sieve analysis, Atterberg Limit and standard proctor test conducted. Stabilized compressed earth blocks were cast with various percentage of cement (2.5%, 5%, 7.5% and 10%), these compressed earth blocks were tested on unconfined compressive strength at 7, 14, and 28 days of curing. The strength of the sample increases with increasing of cement content and curing days. The highest compressive strength of compressed earth block achieved was 3.4 N/mm² with 10% of cement content at 28 days of curing. These 28 days UCS of cement treated laterite soil meets the minimum strength requirement which are 2.8 N/mm² and 1.4 N/mm² for load bearing internal wall and non-load bearing partitions as stated in Malaysian Standards.

1. Introduction
As the population increases in the country, the demand for housing also may increases. Housing cost has been one of the main issues in Malaysia due to the increase in population especially in urban areas mainly due to the immigration of people from rural areas. This is due to urban areas provide more opportunity for the employment [1]. Mostly, they are having difficulties in searching for houses due to the high cost of houses in urban areas. With overcrowding, shortage resources in developing countries and also the used of conventional building materials that require high cost has become the major problem to the developers. As an alternative solution to these problems, using low-cost housing material will be one of the effective solutions needed as to fulfil the basic needs of human being especially for those who have low source of income. In addition, using eco-friendly construction material has become one of the main concerns globally in these recent years. Thus, efforts have been taken by the government and developers in order to provide cost effective, lower energy consumption and less waste production of construction material for sustainable and affordable buildings. Ideally, locally accessible raw material which are abundant in quantity and renewable in nature allows progression of low-cost housing.
Soil has been one of the important construction materials due to its common availability on earth. It is one of the basic materials for the production of blocks. As reported by [2] laterite is suitable to be used for the construction material, this is because when laterites are dried out, irreversible hardening always occurs. Laterite soil are commonly used as road pavement materials to provide a better sub base, gravel for roads and base materials. They are also good material for embankment construction [3]. Several precautions need to be taken when collecting soil for use of road and embankment as those laterites are usually found in thin strata and shallow depth conditions. Stockpile of laterite must be with care to avoid contamination because laterites varies with depth, quality and thickness. Some laterite soil with lower sand size fraction and gap graded having uneven amount of fines and unstable percentage of coarse particles which lowers their engineering performance. To make them useful as a construction material, the soil needs to have soil improvement to enhance its engineering properties.

Cement has proven to be a great stabilizer and reduce swelling percentage of the soil by forming stiff framework and dimensionally stable unit. Ordinary Portland cement (OPC), is the most commonly used stabilizer in most of the past research and currently used in compressed stabilized earth block (CSEB) industries due to its ability to achieve high strength within 28 days. [4] indicated several important effects when soil have reached optimum stabilization such as strength and cohesion property of soil is high, durability of soil increases, swelling and shrinkage of soil reduced in wet and dry surroundings. [5] also showed the maximum strength is achieved with the mix of sand (70%), clay (20%) & OPC (10%). [6] included a technical specification on soil cement block the suitable composition are 15% gravel, 50% sand, 15% silt and 20% clay. They speculated that 4-7% of cement by volume of dry soil is capable of producing 4Mpa blocks while 7-10% cement content to produce 10MPa blocks.

Soil cement blocks have better engineering properties compared to burnt bricks where soil cement blocks provide energy saving as compared to regular material such as burnt bricks. This is because bricks consume a lot of fuel to combust the bricks while soil cement blocks utilize local soil and labour. Besides, blocks are larger in size compared to bricks. Soil cement block production only uses up to 25-30% of burnt bricks process. [6] highlighted that CSEB consumes 11 times less energy and 13 times less polluting compared to fired bricks. The standard process consists in preparing 90% of the moisture with soil and 10% with cement stabilizer [7]. [8] concluded that laterite interlocking block is cheaper both in terms of cost per square metre and unit cost. The interlocking blocks might not require external rendering and also aesthetically pleasing. These CSEB technology have gain popularity in countries like Africa, Latin America and Asia. They have been used for the construction of houses, schools, public facilities, soundproofing walls, furnaces and interior division walls [9]. The Mapungubwe National Park Interpretive Centre, South Africa built with soil cement tiles. They have replaced fired clay bricks with more energy saving stabilized earth tiles. These environmentally sustainable earth material has achieved remarkable 30% cost effective compared to construction using reinforced concrete. Masonry walls made from CSEB have many benefits such as good thermal insulation, their special format of blocks help to elevate wall easily, environmentally friendly, economical, sustainable, and durable.

This study aims to use the laterite soil as an earth material stabilized with cement for the production of compressed earth block. Therefore, a better understanding on geotechnical properties of soils needed to utilize the benefits fully in construction work. Even though gradual success has been achieved by all the research on laterite soil cement block, still the study needs to be more in depth to further implement full benefits of the laterite soil since Malaysia is a tropical country where laterite soil can be found in this tropical area.

2. Experimental methods

2.1 Laboratory works

Laterite soil was used in this study as an earth material for production of compressed stabilized earth block. Sample of laterite soil were collected near Sungai Buloh, Selangor where the area around Sungai Buloh has been experienced alternating dry and wet periods. The soil sample was rusty red in colour which also an indication of high iron oxide content. The sample was collected at a depth of approximately 1.5 meter below the ground surface. Ordinary Portland Cement (OPC) was used in this
study to stabilize the laterite soil for strength improvement. Several laboratory tests were carried out on the soil sample in accordance to BS 1377: Part 2: 1990 [10] that include moisture content, sieve analysis, Atterberg Limit, and standard proctor test in order to obtain the physical properties of the soil. Unconfined compressive strength test was conducted to study on the mechanical properties of the compressed stabilized earth block.

3. Result and discussion

3.1 Moisture content test

As presented in Table 1, natural moisture content obtained in this study was 17.04%. In Nigeria, low and high natural moisture content values are encountered despite having similar climatic conditions. The natural moisture content in most of the samples was close to the moisture content of the plastic limit. Another influence in degree of natural moisture content are clay contents. High clay content in soils have more close arrangement of particles and less pore spaces for moisture to be captured. Unlike sand/gravel, more pore spaces between them makes them pervious to water.

Table 1. Comparison values of natural moisture content of laterite soil with past researchers

| Location       | Depth from ground level (m) | Range of moisture content, w (%) |
|----------------|----------------------------|---------------------------------|
| Sungai Buloh   | < 1.5                      | 17.04                           |
| Batu Pahat [11]| 1.5                       | 22.54                           |
| Nigeria [12]   | 2                         | 12.3 - 22.2                     |
| Nigeria [13]   | < 1.2                      | 13.40                           |

3.2 Particle size distribution test

Figure 1 shows the graph of particle size distribution of soil. It shows a smooth distribution curve with no gap gradation. The curve shape indicate as good gradation as the soil particles are varying from gravel to clayey sizes. According to [14], the mixing ratios of production compressed stabilized earth block prototype mainly consist of sand soil which may significantly affect its performance and durability. Based on analysis result on laterite soil, it was found that the soil containing 12.70% gravel, 53.20% sand, and 34% clay and silt which obviously shows that the highest percentage soil composition is sandy soil. Besides, based on [15], it is recommended that for CSEB production the percentage composition should be within the range of 5-40% clay, 10-30% silt, 25-80% gravel, and fine gravel. Thus, these indicate that the laterite soil is suitable to be used as an earth material for CSEB production. In addition, [16] suggested that the soil with a well-graded criteria and with a sizable fine content may be beneficial during handling on demoulding of CSEB. Uniformity coefficient, Cu obtained is 6.9 which is greater than 6, this shows that soil is well graded and consists of large range of particle sizes in the soil.Cc obtained is 0.74, thus these laterite soil can be categorized with group symbol of SC (Sandy Clay) as accordance to American Society and Testing Material (ASTM) [17].

Figure 1. Particle Size Distribution Curve
3.3 Atterberg limit test

This test has been conducted in order to determine the consistency of fine grained soil. Cone penetration method was used to ascertain plastic limit, liquid limit, and plasticity index of the soil samples. The result analysed shows that the plastic limit obtained is 24.06%. The plastic limit results of laterite soil obtained in this study were close to the result obtained from [18] and also [14] which was 24.32% and 23.10% for laterite soil. Based on Figure 2, it was found that the equation of the line of best fit is \( y = 1.5955x - 44.034 \). From this equation, the liquid limit obtained was 40.13%. This value is the water content data obtained from Figure 2 which corresponds to 20mm of cone penetration.

![Cone penetration vs Moisture Content](image)

**Figure 2. Liquid limit**

The plasticity index obtained in these study was 14.06%. This indicate that laterite soil fulfils the requirement to be stabilized with cement stabilizer since the plasticity index obtained is within 15% as indicated in [10] and [6].

By referring to the plasticity chart in Figure 3, the result shows that the laterite soil is inorganic clay with low plasticity, CL. Some of these properties is that it absorbs less water, it has high degree of permeability and has high shear strength when compared to CH. [19] concluded that the higher the content of fines in laterite soil, the higher will be the plasticity of the soil which consequently reduces permeability of the soil. Based on soil engineering properties chart as stated in [20], these category of clay are characterized as impervious which helps in resisting erosion due to water. This has an important role in the production of CSEB where water content is the major effect to the durability of the block. Laterite soil consisting of impervious clay which helps in reducing the effects of excessive water.

![Plasticity chart](image)

**Figure 3. Plasticity chart**

Table 2 shows comparison of Atterberg limit of laterite soil with past researchers. Most of the values of LL, PL and PI varies according to different locations. This is due to uncertainty in the formation of
mineral constituents of laterite soil which solely depends on the climatic conditions. However, most of the laterite soil plasticity index plots slightly above A-line which clearly classifying it as low plasticity of clay.

Table 2. Atterberg’s limit comparison of laterite soil with past researchers

| Location        | Liquid Limit | Plastic Limit | Plasticity Index | USCS Classification |
|-----------------|--------------|---------------|------------------|---------------------|
| Sungai Buloh    | 40.59        | 26.53         | 14.06            | CL                  |
| Batu Pahat [11] | 54           | 23.1          | 30.9             | CL                  |
| Nigeria [12]    | 40.5 – 59.7  | 16.6 – 32.1   | 23.9 – 32.5      | CH & CL             |
| Nigeria [13]    | 45.5         | 31            | 14.5             | CL                  |

[21] included the suitability of low plasticity index of clayey soil to be stabilized with cement. Since the PI value of laterite soil collected from Sungai Buloh falls in the range of less than 15%, there will be a low degree of expansion occurs when it absorbs water. Hence, less problem will occur with soil having PI less than 15% when stabilized with cement as highlighted by the previous researcher. High value of PI of laterite soil from different parts of the globe observed from Table 2 are highly expansive making those values less suitable to be admixed with cement. From these observations, it can be noted that Atterberg’s Limit can be varies with soil condition, soil mineral constituent, natural moisture content and climatic change occur in a particular location.

3.4 Standard proctor test
In production of CSEB, compaction is done to achieve rigid layer of soil with improved engineering properties. In order to obtain the optimum moisture content of the soil, a series of soil were prepared within the range of natural moisture content obtained. The analysis result of optimum moisture content and maximum dry density of soil is significant as a guidance for sample preparation of CSEB. Moisture content give significant effect on the durability and strength performance of treated soil material. According to [22], if the block is in a very wet state, the mortar has the probability to float on the surface not gaining a good adhesion. Other than that, the water will be quickly sucked out of the mortar if the block is in dry condition which do not allow a good hydration and adhesion of the stabilizing material which is cement. Based on Figure 4, it can be seen that the dry density of soil increases with increasing moisture content until it reaches a maximum point, a reduction in dry density is observed. The result shows that the maximum dry density is 1.88 g/cm³ and the optimum moisture content obtained is approximately 16%. These results of compaction test on laterite soil were compared with [23], in which the maximum dry density that obtained was in a range of 1.84 – 1.85 g/cm³ and optimum moisture content of 13-15%.

![Dry density vs Water Content](image)

Figure 4. Compaction curve of laterite soil

3.5 Unconfined Compressive strength test
Compressive strength of earth block was tested on compression testing machine to determine the soil strength and effectiveness of the laterite soil stabilized with cement. It also functions as a general index to characterize CSEB. A total of 45 of soil samples mixed with various cement content which are 2.5%,
5%, 7.5% and 10% percentage by weight were prepared and crushed with respect to different curing period which is at 7, 14 and 28 days.

Table 3. UCS result of laterite soil with various OPC % and curing period

| OPC content (%) | Compressive Strength $\left(\frac{N}{mm^2}\right)$ |
|-----------------|-----------------------------------------------|
|                 | Curing Period                                  |
|                 | 7 days | 14 days | 28 days |
| 0               | 0.12 | 0.12 | 0.13 |
| 2.5             | 0.46 | 0.6  | 0.89 |
| 5               | 0.87 | 1     | 1.4  |
| 7.5             | 1.47 | 1.76 | 2.5  |
| 10              | 1.83 | 2.4  | 3.4  |

Table 3 shows that in general, compressive strength of soil increases with increasing cement content and increasing curing ages. This is due to formation of cementitious product between the soil particles and cement stabilizer which bond them together increasing the strength of compressed earth block. The compressed earth block gained highest compressive strength of 3.4 N/mm$^2$ when stabilized with 10% of cement content at 28 days curing period. The maximum of 3.4 N/mm$^2$ compressive strength fulfil [24] and [25] standards of minimum compressive strength of 2.8 N/mm$^2$ and 1.4 N/mm$^2$ for load bearing internal wall and non-load bearing partitions respectively which one or two storey dwelling house construction is possible as indicated in Malaysian Standards [24].

Figure 5, 6 and 7 shows the stress-strain characteristics of CSEB with respect to different curing period. Based on these figures, it can be concluded that different curing period have little effect on the strain behaviour of cement stabilized soil. However, different cement content used to stabilize the earth block shows variation on strain characteristics. The increase in cement content increases the compressive strength of compressed earth block but reduces the peak strain. This indicates that the increase in cement content stabilized with compressed earth block exhibit more brittle behaviour which require smaller strain to reach ultimate failure.
Figure 7. Stress-strain relationship at 28 days of curing

4. Conclusion and Recommendation
Laterite soil was used in this study as earth material whereas OPC was used as a stabilizer to enhance the strength of the laterite soil for the production of compressed stabilized earth block (CSEB). Based on the tests conducted, engineering properties of natural laterite soil was obtained. The soil is categorized as Sandy Clay (SC) with low plasticity of clay according to American Society and Testing Material (ASTM) [17]. Overall, the stress strain curve shows that the stabilization of cement gradually converted its stress strain behaviour from ductile to brittle nature. The maximum compressive strength of compressed earth block achieved was 3.4 N/mm$^2$ stabilized with 10% of cement content at 28 curing ages. As the curing days increased, higher compressive strength is achieved among the stabilized samples. 9-10% cement percentage is recommended to stabilize laterite soil with curing of 28 days is mandatory. The value lies above the required compressive strength of 2.8 N/mm$^2$ of non-load bearing block specified by [25]. As a conclusion, laterite soil stabilized with cement can be used as a sustainable material for the production of compressed stabilized earth block for low cost housing.

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