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Strength Assessment of Improved Adobe Brick Using Natural Stabilizers

Gaspard Ukwizagira[1*] & Leopold Mbereyaho[2]

[1]*Assistant Lecturer, Department of Civil Engineering, Rwanda Polytechnic/IPRC Huye, Huye-Rwanda.*
[2]*Associate Professor, Department of Civil, Environmental and Geomatics Engineering, University of Rwanda, College of Science and Technology, Kigali-Rwanda.*
*Corresponding Author (Gaspard Ukwizagira) - ukwizagiragasp@gmail.com**

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ABSTRACT

Adobe or mud brick building technique is an ancient technique dating back at least to 8300 BC. The oldest continually inhabited structures in the world are made in adobe. Adobe brick have revealed many advantages such as low cost, simple construction, excellent thermal and acoustic properties. Dispute these advantages, adobe buildings experience many problems, like water effect and low brick strength, among others. The objective of this study was to assess the strength of adobe brick made from natural soils and stabilized using laterite, fine sand and fibrous grass. The study first checked the quality of all used materials components, and then with reference to the USCS, the classification and quality of those materials were determined. Afterwards, the controlling brick sample made of natural soil, and the stabilized brick made of natural soils with stabilizers were manufactured using the mix ratio of 50% natural soil, 30% of laterite, 15% of fine sand and 5% of fibrous grass. After the bricks curing, the compressive strength test was performed. It was observed that the adobe brick strength was improved from 1.04 N/mm^2 to 2.128 N/mm^2 after its stabilization. Further studies were recommended regarding the improvement of adobe bricks performance using other soils mixture content, or other types of stabilizers with target to achieve the strength of stabilized soil bricks with cement or even the strength of burnt bricks.

Keywords: *Adobe brick; Atterberg limit; Compressive strength; Fibrous grass; Laterite; Stabilization.*

1. Introduction

1.1. Background

Adobe is one of construction materials manufactured from naturally available materials and used to provide a shelter as a basic need of a man. All efforts for technological advancement in housing field are mostly based on satisfying this need by using high-quality materials. Adobe has been used as a building material for thousands of years. Basic Adobe bricks are made by mixing earth with water, and placing the mixture into moulds and leave drying the bricks in the open air, away from direct sun. Mud mortar is used to join mud bricks together and can also be used as a plaster to cover the internal and external walls (Abdu, 2010; Mbereyaho et al., 2020).

Mud is considered inexpensive, broadly available and environmentally friendly material. It consists of stones, sand, silt, clay, and organic humus. Adobe or mud construction is unsophisticated technique; easy-to-learn, and does not need specialized skills. Approximately 50% of the population in developing countries, including the majority of the rural population and at least 20% of the urban population, live in earthen dwellings. Adobe brick as building material should have a high quality especially in strength in order to make the building structurally and functionally safe. Unfortunately, adobe bricks have low-strength and are a brittle material. Adobe bricks are subjected to cracking due to drying shrinkage which decreases its compressive strength and it needs continuous maintenance to keep his relative working performance, if no other improvements are done. This study is conducted with purpose to manufacture an improved adobe brick by considering a well-mixed design of mud components like soil, fine sand, laterite and with addition of fibrous grasses materials. This improvement was assessed by checking its new strength.

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1.2. Overview on previous studies

Several studies have been carried out all over the world on adobe brick and its improvement techniques. Some of them have been specific on soil stabilization for adobe bricks. Authors would appreciate effort made by all those researchers for their different and relevant findings, while giving an overview just on some of them. In practical, compressive strength value for stabilized earth building blocks may be less than 4MPa and for small building loads like in single story buildings, a compressive strength value from 2MPa to 4MPa may be even sufficient. In his study on adobe bricks as the eco- friendly building materials, Benghida (2015) concluded that adobe bricks treatment with ecological and low cost composants with natural fibers was effective solution to the brick performance improvement. The enhancement of adobe durability by natural reinforcement for propagating sustainable mud housing indicated that durability of stabilized soil samples increased by 72% and 68% for fibers of Grewia Optiva and Pinus Roxburghii respectively, as compared with unstabilized soil samples (Sharma and Vinayak, 2016). The study about effects of straw and rice husk on the compressive strength and tensile strength of adobe brick demonstrated that the compressive strength, among other factors improved (Sasui et al., 2018).

A critical review on recent development of fiber reinforced adobe bricks for sustainable construction, with different waste fibers like Waste tea, polypropylene fibers, pineapple leaves, oil palm fibers, coconut, bagasse, straw fiber, banana fibers, etc., concluded that improved adobe brick properties can be expected with the combination of waste additives (Salih et al., 2020). During their investigation, Dawood et al. (2021) used natural fibers (straw, sawdust, and rice husk) as additives with fine and coarse sand as a stabilizer, and cement as adhesive and cohesive substance of the mud matrix, and established the best mix for compressive and the flexural strengths of bricks. In their study on strength characteristics of earth bricks and their application in construction, Mbereyaho et al. (2014), among other results, established that the addition of grasses in clay-silt brick mixture improved the compressive strength from 1.14MPa to 1.70MPa. The enhancement of compressive strength for adobe bricks using sugarcane molasses and gypsum confirmed that the compressive strength would depend on percentage of clay, and sand fraction, moisture content and percentage of stabilizer (Cuervo, 2020). When earth blocks were stabilized with sand, clay and Ordinary Portland Cement (OPC), among other results, the maximum strength of 3.11N/mm^2 was achieved with 70% of sand, 20% of clay and 10% of OPC (Patowary et al., 2015). Cow dung was also used for improvement of both earth blocks and mortar. The stabilization of earth blocks by cow-dung demonstrated a significant improvement in the water resistance of adobe, and therefore this made it a suitable material for wet climates (Milogo et al., 2018). The development of eco brick and concrete with the partial replacement of cow dung confirmed that produced bricks by partial replacement of clay with cow dung were sustainable eco-friendly, and lighter in weight, but concluded that this replacement resulted in less strength (Magudeaswaran, 2018). An assessment of mortar properties from cohesive soil with cow dung showed good results with 20% of cow dung in the mortar, and concluded that such mortar might be considered as a low-cost alternative plastering material to cement mortar (Mbereyaho et al., 2020). Fibrous grass has been used in earthen construction to increase ductility, tensile strength erosion resistance, and dimensional stability and reduce shrinkage cracks of the materials (Walker, 2004). Fibrous grass and other vegetation used in the making of adobe are a source of nutrition for ants and other life forms. Reptiles, rodents, insects, bacteria, fungi and vegetation species that live in the soil environment play active roles in the degradation of adobe structures; life forms that feed off plant roots in the adobe structure cause the weakening, breakdown and erosion of the adobe by opening channels to reach the roots of these plants (Gayurfar, 2009).

Therefore, the main drawback of adobe brick is the need for continuous maintenance and the lack of durability and resistance to water. Based on this fact, this research was decided to analyze how adobe brick strength may be improved and stabilized by adding other materials and stabilizers so that they can structurally last longer. It can be seen that different ways of improving the performance of adobe bricks, have been considered, in different studies, but not only the stabilizers types were not exhaustive, but also the ideal strength was still to be achieved. Therefore the manufacturing of adobe brick using ordinary soil, fine sand, laterite and fibrous grasses and its strength assessment are analyzed and respective results presented.

2. Methodology

The manufacturing and improvement of adobe bricks require detailed knowledge of earth classification, stabilization techniques and earth properties. During this study, the following methodology was applied: Field survey and soil sampling, field and visual test, laboratory soil test, adobe brick manufacturing and drying, as well as laboratory tests.

2.1. Field survey and sampling

The field survey was organized to observe the situation of adobe brick application. Then a soil sample with black color was randomly collected for use in this study. The soil was mixed with fine sand and fibrous grass and laterite as stabilizers.

2.2. Laboratory tests

During this study, manufactured adobe bricks were tested in order to investigate on strength change. Before brick manufacturing, tests were performed with laterite, natural soil and fine sand to ensure their quality. The following tests were performed: Sieve analysis and Atterberg limits, including liquid limit and plastic limit tests were carried out on laterite, natural soil as well as on fine sand. The compressive strength was performed on manufactured adobe brick samples. All results are presented in section4.

2.3. Manufacturing of adobe bricks

The following were key steps followed during manufacturing:

✓ The sampling of all used components, including the soil, fine sand, laterite which are all available in Rwanda different regions.

✓ Used natural fibrous grasses were collected from one of local village, Jabana forest in Gasabo district (Kigali city), and dried in ventilated area during 4 days to increase its capacity against decaying.

✓ The tests on the collected adobe materials were conducted to assess their properties.

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✓ All the materials used for manufacturing adobe brick, which included soil, laterite, fine sand, fibrous grass and water, were mixed together under the proportions of 50% natural soil, 30% of laterite, 15% of fine sand and 5% of fibrous grass. Used fibrous grass was cut into fibers of average length equal to 5cm (in a range between 2cm and 6cm), with 1mm to 2 mm in diameter.

✓ The molding was conducted using wooden formwork of 34cm×16cm×14cm for internal dimension. Each mixture was compacted manually by hands into wooden formworks; eight samples were molded manually by hand where 4 controlling samples were made of soil only, while other 4 samples were made of soil with stabilized materials. Water in cloth process was used during molding to allow the sticking of the wet mud with the wooden pattern during casting. After molding, adobe bricks were exposed to sun for drying during two weeks.

3. Results

It is worth to note that all graph were drawn based on the tabulated results, which could not be presented here.

3.1. Sieve analysis test for laterite

As it was stated in section 2, the sieve analysis test was conducted to determine the particles size distribution of laterite. Fig.1 shows the results under graph format. It can be seen that the sample was composed with gravel (34.75%), silt + clay (3.12%), and sand (62.12%), and consequently the soil sample was ***sand soil***.

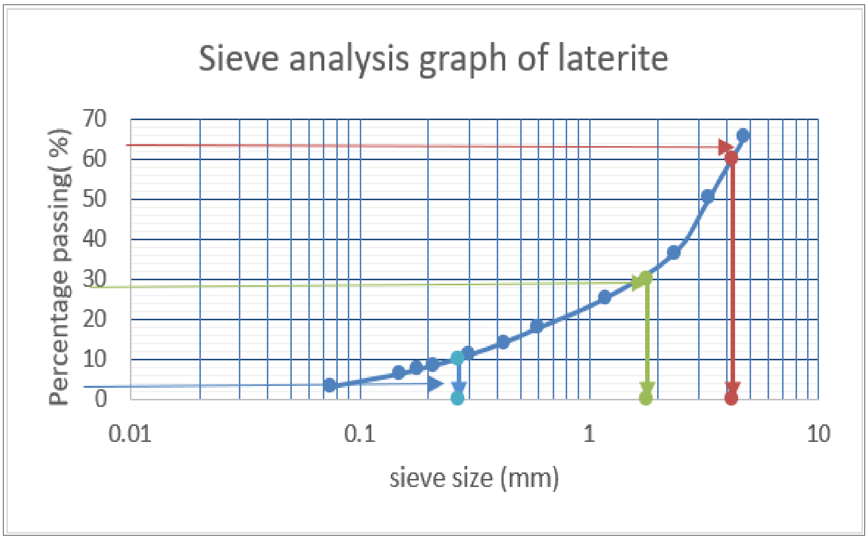

Figure 1. Sieve analysis graph of laterite

Referring to the results in Fig.1, the uniformity coefficient (CU) and the coefficient of curvature (CC) are calculated using the sizes for percentage of finer components, as follows:

1. D60 = 4.2 $CU = \frac{4.2}{0.27} = 15.56$

2. D30 = 1.78 $CC = \frac{1.78^2}{4.2*0.27} = 2.79$

3. D10 = 0.27

As the CU is greater than 6 and the CC lies between 1-3, it is concluded that the soil is ***a well graded sand.***

3.2. Sieve analysis test of natural soil

The graph showing the results is given in Fig.2.

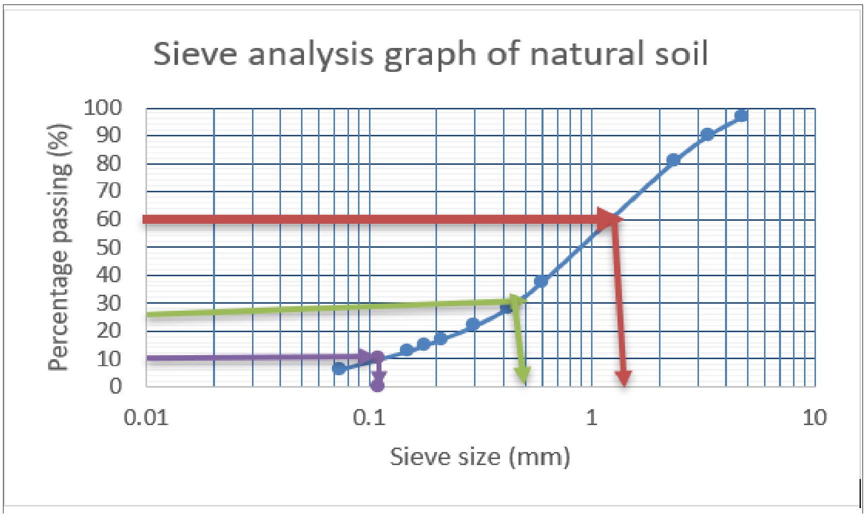

Figure 2. Sieve analysis graph of natural soil

The coefficients CU and CC are below calculated:

1. D60 = 1.3 $\quad CU = \frac{1.3}{0.11} = 11.82$

2. D30 = 0.47 $\quad CC = \frac{0.472}{1.3*011} = 1.544$

3. D10 = 0.11

Fig.2 shows that the soil sample is composed by gravel (3.27%), silt +clay (6.07%) and sand (90.66%) based on this percentage shows that this soil sample is **sand soil**. The computation shows that CU was greater than 6, while CC lies between 1-3, and therefore the considered sample belongs to ***a well graded sand***.

3.3. Sieve analysis test of fine sand

The results are presented in Fig.3.

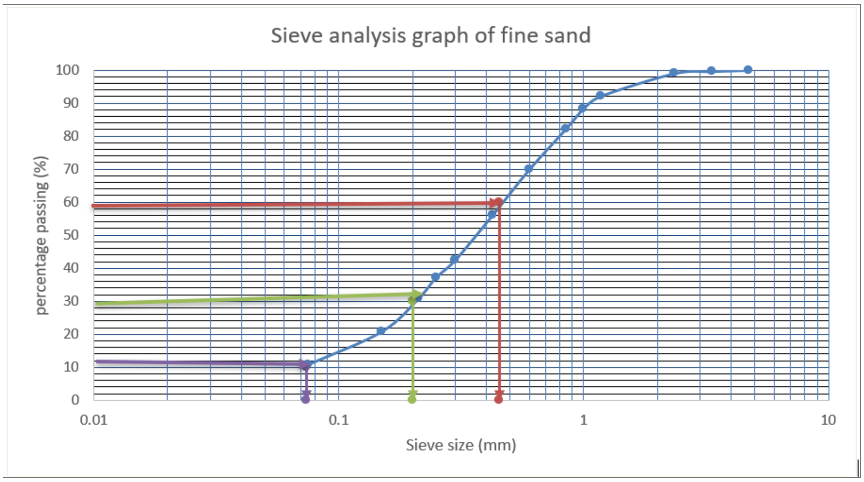

Figure 3. Sieve analysis graph of fine sand

Similarly, the coefficients CU and CC are computed below.

1. D60 = 0.455 $CU = \frac{0.455}{0.074} = 6.15$

2. D30 = 0.2 $CC = \frac{0.22}{0.455*0.074} = 1.19$

3. D10 = 0.074

Consequently, the soil sample represented a ***well graded sand***.

3.4. Plasticity index (PI) of natural soil

3.4.1. Atterberg limit test for natural soil

Atterberg limit test results, respective chart is given in Fig.4.

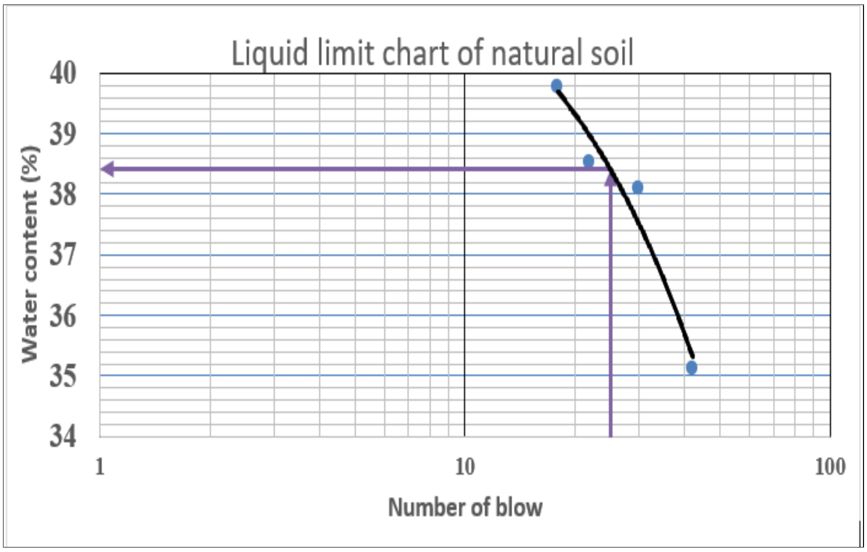

Figure 4. Liquid limit chart of natural soil

According to the chart in Fig.4, the liquid limit at 25 blows is 38.4175

3.4.2. Plastic limit of this soil

It is the average of the water content of 3 trial test sample where it will be equal to: $PL = \frac{14.48+27.5+25.6}{3} = 22.53$

3.4.3. Plasticity index (PI)

It is equal to the liquid limit minus plastic limit: LL-PL; PI=38.4175-22.53 = 15.8875

3.5. Plasticity index (PI) of laterite

3.5.1. Liquid limit of laterite

Liquid limit results chart is presented in Fig.5.

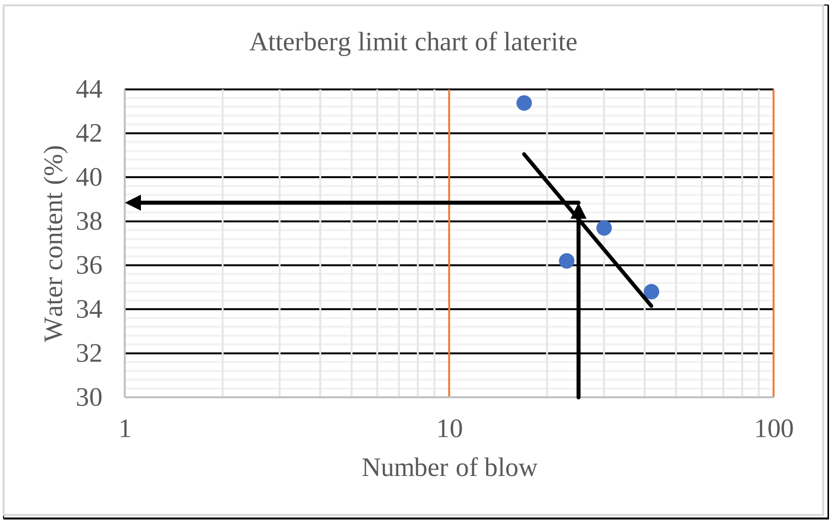

Figure 5. Liquid limit chart of laterite

According to the chart above the liquid limit at 25 blows is 38.85

3.5.2. Plastic limit of laterite

Plastic limit of laterite are presented in table 1.

Table 1. Plastic limit of laterite calculation

S/N	Sample number	1	2	3
1	Can number	019	051	035
2	Mass of can (g)	45.3	44.3	48
3	Mass of wet soil +can (g)	69.9	66.5	77.9
4	Mass of dry soil +can(g)	64.2	61.9	70.4
5	Mass of dry soil (g)	18.9	17.6	22.4
6	Mass of water(g)	5.7	4.6	7.5
7	Water content (%)	30.16	26.14	33.48
8	AVERAGE	29.93		

Therefore, the plastic limit of laterite is calculated as follows:

$$PL = \frac{30.16 + 26.14 + 33.48}{3} = 29.93$$

Plasticity index is equal to liquid limit minus plastic limit (PI), and therefore

PI=LL-PL, PI=38.85-29.93=8.92

3.6. Plasticity index (pi) of fine sand

3.6.1. Liquid limit of fine sand

Results are presented in the following chart (Fig.6).

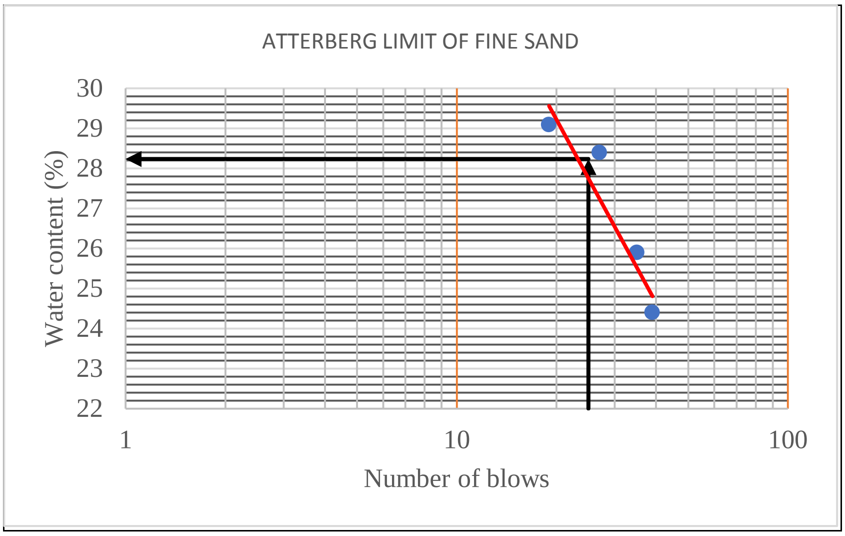

Figure 6. Liquid limit of fine sand chart

According to the chart above, the liquid limit at 25 blows is 28.23

3.6.2. The plastic limit of fine sand

Based on the above chart, the plastic limit of fine sand is therefore calculated as follows:

$$PL = \frac{18.45 + 25.9 + 35.6}{3} = 26.65$$

3.6.3. Plasticity index (PI)

It is equal to liquid limit minus plastic limit (PI)

PI=LL-PL, PI=28.23-26.65=1.58

3.6.4. Test results analysis by plasticity index

By considering the plasticity index and liquid limit of each sample, the classification of soil under Unified Soil Classification System (USCS) can be completed. Under this system the soil is classified either as clayed or is silt, and this clarify the classification from sieve analysis test. Fig.7 shows the Plasticity index chart of natural soil, fine sand and laterite.

Based on the plasticity index chart in Fig. 7, and looking at the position of the Plasticity Chart point with regards to the A-line, with reference to the Unified Soil Classification System (USCS), the following are final classifications:

- The given laterite is well graded sand with clay and gravel.
- The used natural soil is well graded sand with clay.

➢ The considered fine sand is a well graded sand with silt.

At this level, it was suspected that the above classification would influence on the quality of manufactured adobe bricks.

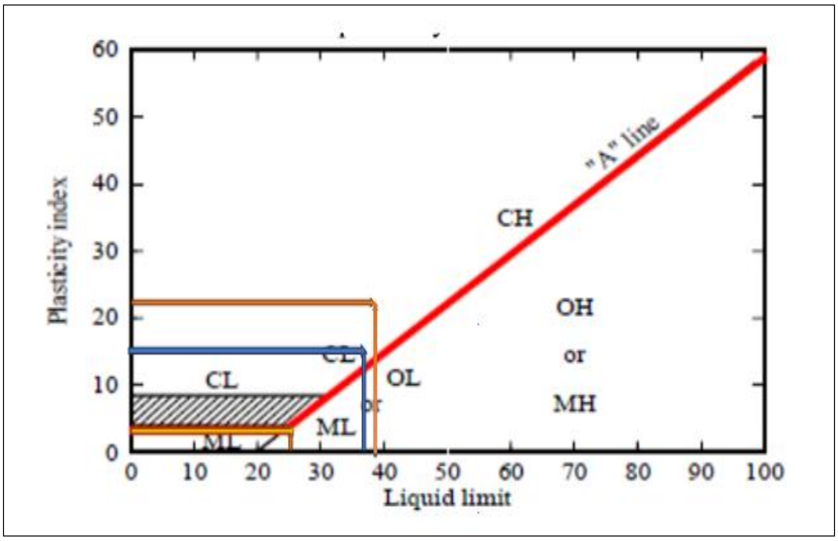

Figure 7. Plasticity index chart of natural soil, fine sand and laterite

3.7. Compressive strength test results

3.7.1. Adobe brick with natural soil

These 4 controlling samples were made only with natural soils. Test was conducted at 21 days after curing. The compressive strength was calculated from the total load applied to the specimen divided by the cross-sectional area of the specimen. Results are presented in table 2.

Table 2. Compressive strength of adobe brick made of natural soil

SN	Actual size of brick (cm)	Compressive load (KN)	Compressive strength (N/mm^2)
1	34×16×14	57.12	1.05
2	34×16×14	59.84	1.1
3	34×16×14	52.56	0.97
4	34×16×14	56.57	1.04

The average compressive strength is equal to $\frac{1.05+1.1+0.97}{3} = 1.04N/mm2$.

3.7.2. Adobe bricks with stabilizers

The bricks were manufactured mixing 50% of natural soil, 30% of laterite, 15% of fine sand and 5 % of fibrous grass. Results are presented in table 3.

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Table 3. Compressive strength of adobe brick with stabilizers

SN	Actual size of brick (cm)	Compressive load (KN)	Compressive strength(N/mm^2)
1	34×16×14	119	2.187
2	34×16×14	111.2	2.044
3	34×16×14	115.4	2.121
4	34×16×14	117.6	2.162

The average compressive strength is $\frac{2.187+2.044+2.121+2.161}{4} = 2.128N/mm2$

4. Discussion of results

During this study, the improvement of adobe brick compressive strength was achieved by its stabilization using fine sand, laterite and fibrous grasses. The classification of these materials as per USCS explains the particularity of achieved results in the study. The controlling brick made with only natural soils showed a compressive strength of 1.04 N/mm^2, while the stabilized brick showed 2.128 N/mm^2. From these results, it can be seen that a clear improvement was achieved. The results go well with some standards requirements, where some of them state that the compressive strength should range between 2-3 N/mm^2 (IS 1725, 1982). Also, if comparing with other previous published results, this compressive strength is adequate and, in some cases, even better (Benghida, 2015; Mbereyaho et al., 2014). The good result was achieved due to the reasonably increased amount of clay in the used soils as it improved the cohesion and increased the strength (Krishnaiah and P. Suryanarayana Reddy, 2008). Other reason may be in connection with the presence of fibrous grasses in the content, as fibres can reduce hygrometric shrinkage and release water slowly (Sasui et al., 2018; Quagliarini and Lenci, 2010; Mbereyaho et al., 2019). This compressive strength is however still lower than for the one in which stabilizers included cement (Patowary, et al., 2015). The results show that the manufactured adobe brick would fit for single story buildings. More studies to increase the adobe brick weather resistance is recommended to ensure its sustainable application

5. Conclusion

This objective of this study was to assess the strength improvement of adobe brick made with some stabilizers. The stabilization of adobe bricks from natural soils was done using laterite, fine sand and fibrous grass, in the following mixture content: 50% of natural soil, 30% of laterite, 15% of fine sand and 5% of fibrous grass. First the study checked the classification and quality of all materials components by tests. With reference to the USCS, it was showed that the added laterite was well graded sand with clay and gravel, the natural soil was well graded sand with clay, while the considered fine sand was well graded sand with silt. Afterwards, the two types of bricks sample were manufactured: controlling brick sample made of natural soil, and improved brick made of natural soils with stabilizers. After manufacturing bricks and conducting some tests, including the compressive strength test, it was observed that the strength of natural soil brick was found equal to 1.04 N/mm^2, while adobe brick produced with stabilizers showed a good compressive strength equal to 2.128 N/mm^2. Therefore, it can be concluded that that the stabilization described in the study improved greatly the adobe strength. Further studies may check the improvement of adobe bricks not only regarding the strength, but also the durability, using other soils mixture content, or other types of stabilizers with target to achieve the strength of stabilized soil bricks with cement or even the strength of burnt bricks.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this research work.

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