Utilization of lightweight brick waste as soils stabilizing agent

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Submission date: 07-Jan-2022 07:22PM (UTC+0700)
Submission ID: 1738487140
File name: 2020_Arifin_2020_IOP.pdf (776.75K)
Word count: 4169
Character count: 19902

IOP Conference Series: Materials Science and Engineering

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Abstract. The utilization of lightweight bricks as building walls, including houses, is getting higher. Beside its many advantages, lightweight brick also has disadvantages. One of them is that the remaining pieces cannot be used for its primary function and become waste. In the field, this waste is used as a material to stabilize the soil. However, there are no tests that examine its effectiveness as a stabilizing agent, the percentage of its composition, and what soil can be stabilized. This research focuses on laboratory tests on the use of lightweight brick waste for soil stabilization. The types of soil used in this study were lateritic, organic and expansive soil. The soils and waste were mixed at percentages of 2%, 4%, 6%, 8%, and 10% by weight. Some tests, such as the Atterberg limit, Standard Proctor compaction, and unconfined compression tests were carried out to determine its effect on the soil. The results showed that lightweight brick waste reduced the liquid limit, plasticity index, and increased soils shear strength. Different types of soil produced different levels of influence. Moisture content in the mixtures was also found to affect the results of soil stabilization.

1. Introduction

Lightweight brick has been widely used in the world since the 1980s, including Indonesia. Due to its high demand, one lightweight brick manufacturing company in Indonesia can produce one million cubic meters per year.

There are two types of lightweight bricks, namely Cellular Lightweight Concrete (CLC) and Autoclaved Aerated Concrete (AAC). The type commonly used today is the AAC. Its main ingredients are quartz sand, cement, lime, a little gypsum, water, and aluminum paste. The CLC type is rarely used because it is made of a material containing fly ash, which is still considered hazardous waste.

Lightweight brick has advantages over other conventional bricks. Aside from being lightweight, it attributes include low water absorption and high strength that qualifies it as a concrete brick walls [1]. However, the disadvantage of using lightweight bricks is that the remaining pieces cannot be used anymore. This is because the installation requires a flat surface and a thin distance between bricks. A survey in one real estate in Banjar District found that an average of $1m^3$ waste was produced from every $20m^3$ of lightweight brick used.

In Dian Anugerah Regency's real estate in Banjar Regency, the lightweight brick waste was mixed with soil embankment. A field dynamic cone penetrometer (DCP) [2] test was carried out on the soil with and without lightweight bricks. This resulted in the California Bearing Ratio (CBR) of 8.1% and 4.3%, respectively. The addition of the waste has succeeded in increasing the soil's bearing capacity almost two times. However, there is no study about the optimal percentage of lightweight brick

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addition to achieving maximum strength and soil water content suitable for the mixture. A research should be carried out to examine the percentage of lightweight bricks in addition to soil.

Many methods have been carried out by researchers to increase the carrying capacity of the soil. This is carried out by mixing it with other materials both with natural ingredients [3–7] and chemistry. These materials include cement [8–10], lime, and fly ash [11,12], and mixtures both (i.e., cement and palm Kernel shell ash)[13]. Some of these materials are residual or waste material from the industry.

Industrial wastes that have been examined as soil stabilization agents include rubber tires [14], [15], tiles [16], and marble [17]. Waste tires and marble are only used as fillers and they require other material agents as additives such as cement or lime. Tile waste can be used as a stabilizing material. It is used as a filler and binder that react with the soil chemically [16]. No research has been carried out on the use of lightweight brick waste as a soil stabilization agent. This research focuses on the use of lightweight brick waste to increase soil shear strength.

2. Materials and Methods

2.1 *Materials used*

2.1.1 Soils. The three types of soil used in this study were lateritic, organic, and expansive soil. Lateritic and organic soils were taken from Banjarmasin and Banjarbaru, respectively. The expansive soil was a mixture of low plasticity clay and commercial bentonite sold as an industrial product. The basic soil properties used were summarized in table 1. Before adding to the stabilization agent, the chemical compound of the soil used was tested using X-ray Fluorescence (XRF) analyzer, and the results are summarized in figure 1.

2.1.2 Light brick waste. Light brick waste used is an AAC type. In this research, the term lightweight brick was abbreviated as LWB for simplification. The LWB had a dry volumetric weight of 650kg/m^3. The chemical composition of LWB was also shown in figure 1. The LWB was crushed and sieved using sieves No. 4 for compaction test, No. 20 for unconfined compression test (UCT), and No. 40 for Atterberg limits before it was used.

Table 1. Basic properties of soils used.

Properties		Soil		
		Lateritic	Organic	expansive
Specific Gravity		2.67	2.61	2.56
Water content	%	20.89	53.26	7.00
Gravel (> 2 mm)	%	7.96	0.31	2.50
Coarse sand (0.6-2.0 mm)	%	9.06	4.90	1.01
Medium sand (0.2-0.6 mm)	%	8.31	4.48	1.22
Fine sand (0.05-0.2 mm)	%	12.47	3.73	4.20
Silt and Clay (0.002-0.05)	%	25.01	35.28	41.64
Clay (<0.002mm)	%	37.19	51.31	49.44
Liquid limit	%	47.80	58.80	80.03
Plastic limit	%	23.98	36.61	25.00
Plasticity Index	%	23.82	22.19	55.03

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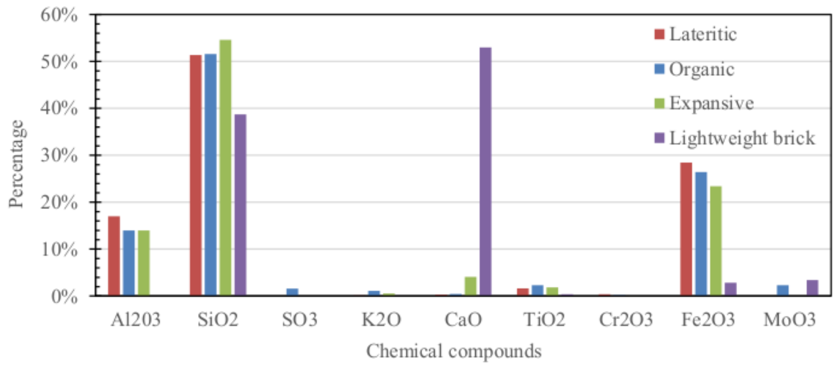

Figure 1. Chemical compounds of material used in this study.

2.2. *Methods and procedures*

2.2.1 Samples preparation. Soils and *LWB* waste samples were mixed by percentages of 2%, 4%, 6%, 8%, and 10% *LWB* content based on the dry weight, after considering the moisture content of the soil. The sample's initial density and moisture content were determined based on the results of the standard Proctor compaction test (ASTM D 698-07) [18]. The standard proctor compaction curves of lateritic and organic clay were shown in figure 2. The maximum dry densities of lateritic and organic clay were 1.7t/m^3 and 1.44t/m^3 respectively. Furthermore, the optimum moisture content of lateritic and organic clay were 20% and 30% respectively. Considering field application, the percentage of 0.95% maximum dry density was used i.e., 1.6t/m^3 and 1.37 t/m^3 for lateritic soil and organic clay respectively. The moisture content of the mixture was also determined by the compaction result (i.e., the moisture content of 15%, 20%, 25% for lateritic soils, and 25%, 30%, and 35% for organic clay). The moisture content and density of expansive soil were assumed to be the same as lateritic soils because of the limited available bentonite. The samples were statically compacted to achieve the density mentioned above.

2.2.2 Physical properties and shear strength tests. The Atterberg limits test [19] was performed to investigate the effect of stabilizing agents on the soil's basic properties. Shear strength compacted samples were determined using the unconfined compression test (UCT) [20]. X-ray diffraction test was also conducted to investigate the effect of the stabilizing agent on the mineralogy of samples.

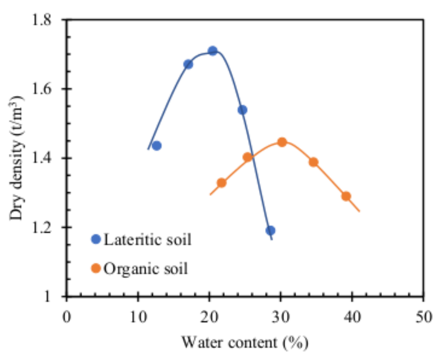

Figure 2. Standard Proctor compaction curves of lateritic and organic soils.

3. Results and Discussion

Figure 3 shows the Atterberg limits test results which include the liquid limit (LL) and plasticity index (PI). Plastic limit (PL) was represented in a plasticity index (i.e., PI = LL-PL). Consistently, each soil's data was represented by different colors, i.e., blue for lateritic, yellow for organic and green for expansive soils. Moreover, the initial data of the soil was presented in black.

Figure 3(a) shows the effect of *LWB* addition to the soil liquid limit. As shown in the figure, the initial LL samples were 80.03%, 58.80%, and 47.80% respectively. Expansive, organic, and lateritic soils were reduced to 74.8%, 54.2%, and 43.1% at 10% *LWB* content. LL samples were reduced by an average of 4%. It can be concluded that LL samples are affected by lightweight brick waste because its value decreases by an increasing percentage of *LWB*.

Figure 3(b) shows a graph of the relationship between the percentage of lightweight brick waste with PI. The initial PI of expansive, organic, and lateritic samples were 55.03%, 22.19%, and 23.82%, respectively, decreased to 54.2%, 17.36%, and 16.36%. Although the LL reduction was little, increasing the percentage of *LWB* also gave rise to PL, as shown by a significant decrease in PI.

Figure 3(c) shows the plasticity chart which was used to determine the soil classification by USCS method (ASTM D2487)[21]. This curve also clarifies the type of soil used in this study, namely clay with high plasticity (CH), organic soil with high plasticity (OH), and clay with low plasticity (CL), respectively, for expansive, organic, and lateritic soils. The addition of *LWB* results in the movement of data towards different soil types, are represented by arrows. This occurred in the lateritic sample that was turned into silt soil with low plasticity (ML). Meanwhile, the other soils turned to silt soils with high plasticity and organic with low plasticity, respectively, for expansive and organic soils. Changes in clay type into silt soils with larger grain sizes indicate the aggregation of clay granules due to the addition of *LWB*.

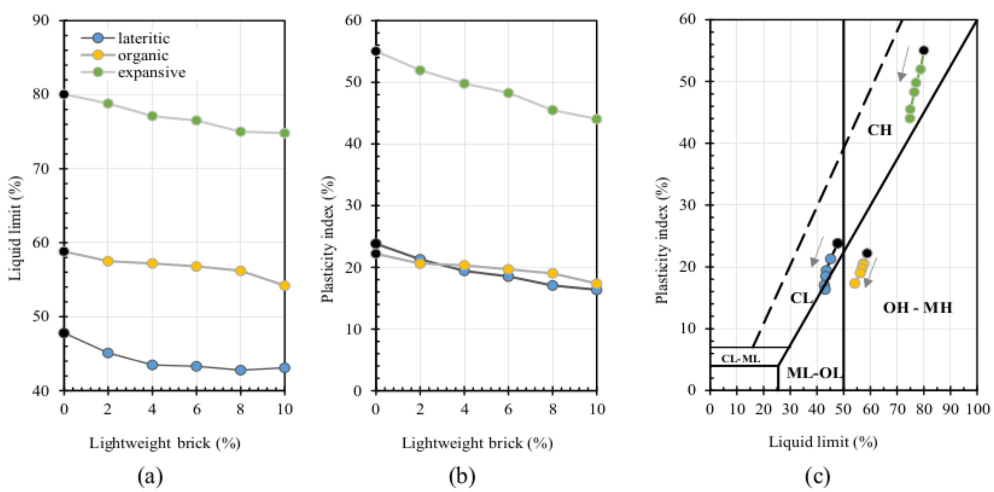

Figure 3. Lightweight brick effects on Atterberg limit of soils.

Figure 4 shows typical UCT results obtained in this study. The figure shows the compressive strength versus strain curves of the materials tested at different moisture contents and represented by 4% *LWB*. As shown in figures 4(a) and 4(b), the samples tested at the optimum moisture content (as shown in figure 2 produced the highest maximum compressive strength (q_u). Conversely, a sample which was compacted at higher moisture content than the optimum moisture content produced the lowest qu. These results show that the samples were still characterized as clay soils. The compaction at

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optimum moisture content resulted to maximum density followed by other beneficial behaviors, including maximum shear strength.

Figure 4(c) shows the curve of compressive strength versus strain relationships for samples of expansive soil mixed with 4% *LWB*. The highest maximum compressive strength was found at the highest moisture content, which was at w = 25%. This happened because the assumptions of the moisture content used for this sample are smaller than its optimum moisture content. The optimum moisture content for expansive soils was generally higher. The addition of bentonite increased soil plasticity and optimum soil moisture content [22]. However, these results provided valuable information where the addition of *LWB* to the soil was carried out. It was implemented at optimum moisture content or smaller to obtain favorable effects. The result shown in figure 5 is the relationship between moisture content and undrained cohesion (c_u) of samples. Undrained cohesion is a parameter of soil shear strength where $c_u = ½q_u$. As shown in figures 5(a) and 5(b), the peak of c_u occurs in a

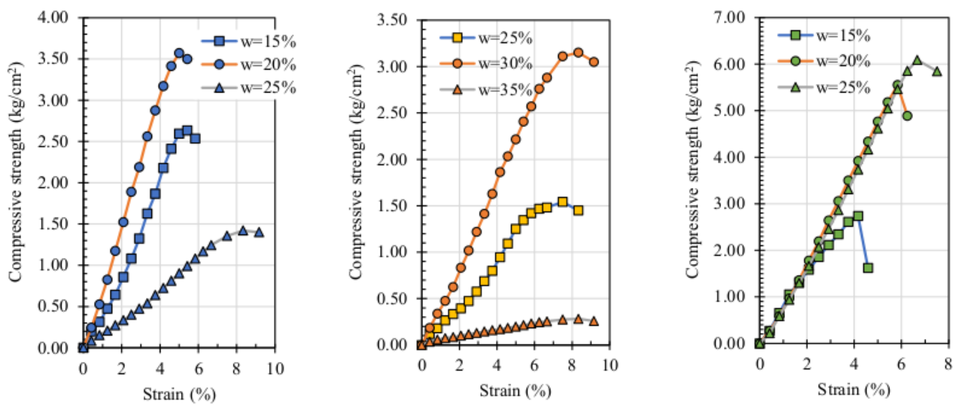


Figure 4. Compressive strength sample versus strain of soils with 4% lightweight brick content (a) lateritic soil, (b) organic soil, and (c) expansive soil.

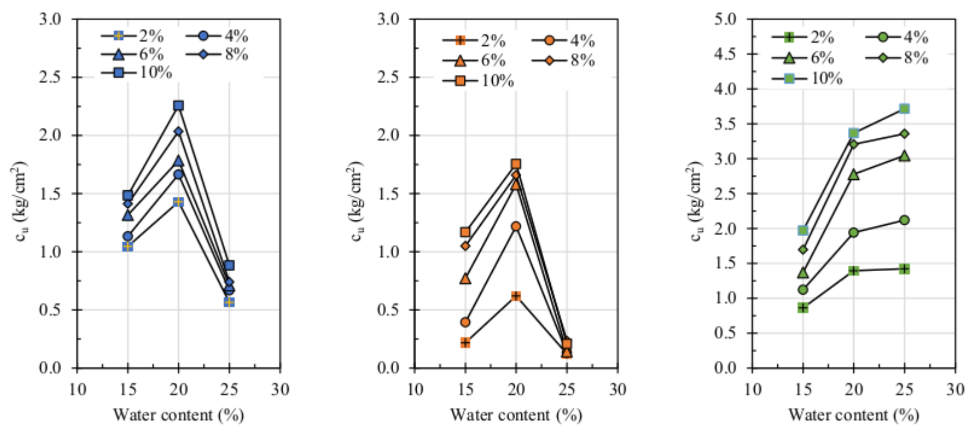


Figure 5. Cohesion undrained of compacted soils-LWB mixtures as a function of water content (a) lateritic soil, (b) organic soil, and (c) expansive soil.

compacted sample at the optimum moisture content for lateritic and organic soils. Furthermore, for expansive soils compacted at moisture content less than the optimum moisture content, the c_u increased by the rise of moisture content.

Figure 6 shows the undrained cohesion of the sample as a function of mild brick waste content. Figure 6(a) shows the c_u value of the sample compacted at the lowest moisture content (or at dry of optimum for lateritic and organic soils). For lateritic soils, cu increased from 1.23 kg/cm^2 to 2.26 kg/cm^2 or increased 1.8 times at 10% LWB percentage. Similar results were also obtained in the organic-*LWB* clay mixture where c_u increased from 0.24kg/cm^{2}to 1.76kg/cm^2 or increased 7.5 times at the addition of 10% *LWB*. c_u increases by the rise in the percentage of lightweight brick waste. The highest increment is seen in figure 6(b) for samples compacted at the optimum moisture content (i.e., lateritic and organic soils). As for expansive soils, the value of c_u increased from 0.926kg/cm^2 to 3.37kg/cm^2 or 3.6 times at 10% *LWB* content.

Figure 6(c) shows the c_u sample compacted at higher moisture content than the optimum moisture content (also called the wet of optimum) for lateritic and organic samples. As shown in the figure, c_u lateritic samples 0.55kg/cm^2 at 2% *LWB* increased to 0.88kg/cm^2 or 1.6 times the initial c_u. For organic soils, c_u increases from 0.12kg/cm^2 to 0.21kg/cm^2 or 1.7 times at 2% and 10% *LWB* content. These values are smaller than c_u samples without *LWB* compacted at the optimum moisture content (figure 6(b)). Different results were seen in expansive soils compacted at the dry of optimum. c_u increased significantly from 1.62kg/cm^2 at 2% *LWB* to 3.72kg/cm^2 at 10% *LWB*. This result confirmed the previous results where the best result of *LWB*-soil mixtures was compacted at the optimum moisture content or less.

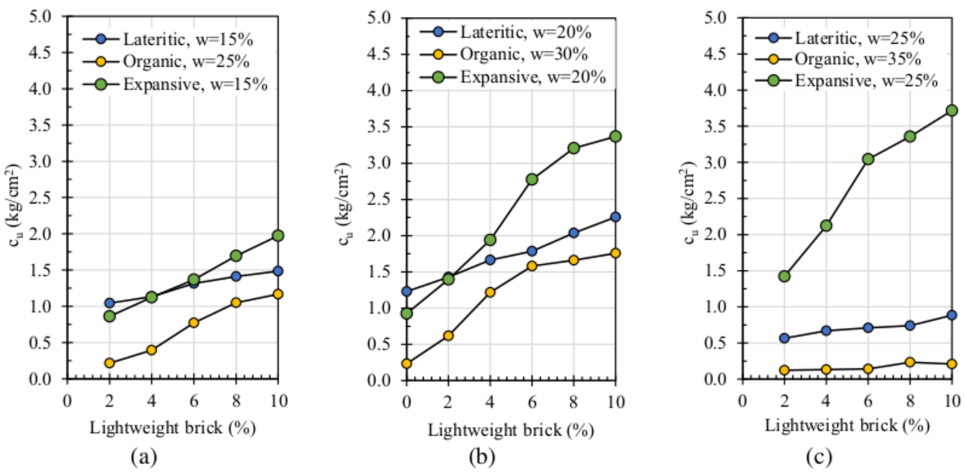
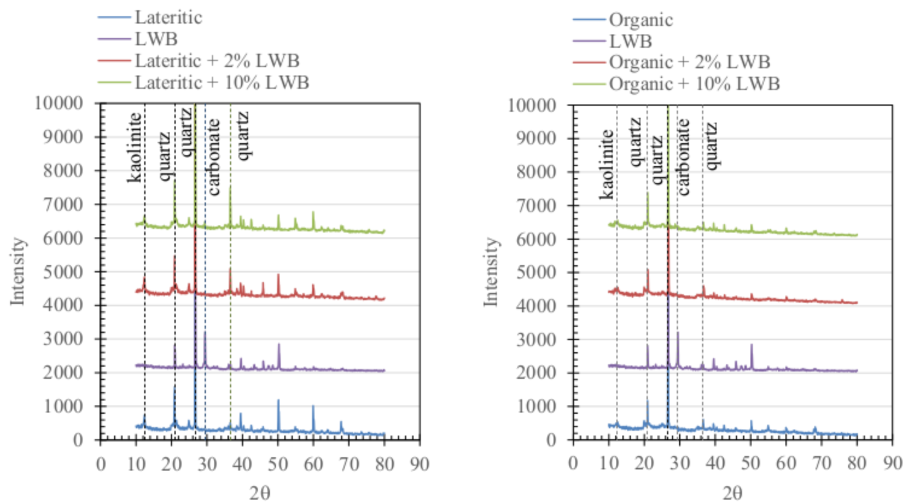


Figure 6. Cohesion undrained samples as a function of LWB content.

Figure 7 presents the results of X-ray diffraction analysis conducted on soil samples. This was mixed with 2% and 10% *LWB* at optimum moisture content for lateritic soils organic clays. As shown in figures 7(a) and 7(b), lateritic soils and organic clays contained dominant kaolinite and quartz. Furthermore, *LWB* contained dominant quartz and calcite (CaCO3). The presence of calcite was confirmed by comparing it with the XRD pattern reported by [23]. From figure 7(a), an increase in the intensity of quartz is recognized at 2θ between 30^o-40^o followed by the loss of the calcite peak at intervals of 25^o-30^o. This behavior showed an increase in ionic bonds with Si producing SiO. Figure 7(a) also revealed the emergence of low-intensity calcite peaks in lateritic soils added by 10% *LWB* due to the remaining non-bound calcites.

The XRD results of organic clay and *LWB* mixtures are shown in figure 7(b). There was little change in the intensity and peaks in both samples with 2% and 10% *LWB*. Change only takes place in an increase in quartz intensity. These results confirmed that the ionic bond was not stable. Therefore, the excess water in the sample resulted in a slight increase in the sample's shear strength. This was obtained for lateritic and organic samples compacted at the high moisture content (figure 6(c)).



(a) (b)

Gambar 7. X-ray diffraction result of lateritic and organic soils-LWB mixtures.

4. Conclusions

Stabilization of lateritic soils, organic clays, and expansive soils using lightweight brick waste has been presented and discussed. LL and PI samples were affected by *LWB* because the values decreased by an increase in the percentage of waste. The rise in the percentage of *LWB* waste also increased PL shown by significantly reducing PI values. The tendency for soil to change occurred by an increase in the *LWB* content. The data evolution in the plasticity chart indicated the result.

Increasing the *LWB* percentage also raised the shear strength of the soil, as designated by an increase in undrained soil cohesion. Initial moisture content affected the shear strength of the *LWB*-mixed soil sample. Compactions at optimum moisture content or smaller produced the best effect of *LWB*. Conversely, compactions at higher moisture content than the optimum produced less shear strength than the soil's strength without a stabilizing agent. The XRD results confirmed the presence of ionic bonds by reducing the calcite peak and increasing the intensity of the quartz peak of soils-*LWB* mixtures.

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