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Research Article

Application of Optimum Compaction Energy in the Development of Bricks Made with Construction Trash Soils

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In general, bricks frequently show different densities and therefore different resistances because the compaction energy is not considered in their production. Expansive soils represent a problem for light buildings over them because of volumetric instability. A generalized solution has been to extract them and substitute them by inert soil; thus they become construction trash. So, in this work the compaction energy aspect and the use of construction trash soils in the elaboration of resistant masonry bricks of homogeneous and controlled density are a new contribution in the production of bricks of better quality. First, the soil was stabilized with CaOH which leads to a decrease in its volumetric changes. Then, they were compacted with a specific energy for obtaining an optimal and maximum controlled density to ensure an increase in strength. Our results show that two optimal compaction energies can be considered with respect to the variation of optimum moisture in masonry bricks of expansive soil stabilized with lime. The first is when the optimal humidity reaches its smallest value (integrated soil lumps) and the second is when humidity increases (disintegrated soil lumps), after reaching its lowest value. We also conclude that high compaction energy does not improve density values.

1. Introduction

Many countries in the world have to deal with the problem of expansive clays (vertisols) such as Mexico, the USA, Australia, South Africa, India, and Israel among others. In particular several regions of Mexico, for instance, in the lacustrine planes located at the states of Querétaro, Guanajuato, Michoacán, Tamaulipas, Morelos, Sonora, Baja California, Veracruz, Chiapas, and Campeche, deposits of this type of soils can be found. The constant growing of human settlements has provoked the urban stain to be extended up to agricultural lands, thus forcing to build on top of them. These soils are mainly of the expansive type and show volumetric instability due to humidity variations. Because of their expansion they bring out fissures in light constructions above them [1]. Due to this problem, these soils are replaced by soils with inert features [2], thus remaining as trash soils. The objective of this study is to use this trash expansive soil via a composite material, soil-CaOH, to produce bricks of optimal and controlled compaction energy for masonry, which is neglected in the production of this kind of bricks.

To achieve this, the trash expansive soil was stabilized with CaOH to eliminate its volumetric changes and then it was compacted at different energies per volume (cubic meter) for controlling different densities and to obtain an optimal-controlled density and optimum moisture to assure a larger strength in the material. Then, test specimens with these densities were made and subjected to unconfined compressive tests. The compaction energy was selected to be the best reasonable strength. Thereafter, masonry bricks were subjected to tests of stress rupture and strength to first fissure.

In general, bricks frequently show different densities and therefore different resistances because the compaction energy is neglected in the production of this kind of bricks. So, the compaction energy aspect in this work is a new contribution in the production of bricks of better quality.

Therefore, after determining the ideal specific compaction energy of a lime-treated expansive soil, we will be able to use the resulting values of maximum density and optimum moisture, which can be applied with some bricks compressor. With this procedure, sustainable bricks of high and homogeneous resistance can be obtained.

2. Background

The applications of the use of soils treated with CaOH are, for example, in the construction of bed-layers of pavements, in the stabilization of dams made of earth, and as a layer for supporting shallow foundations [3]. This technique is conventional for improving expansive soils properties [4]. This is so, because the CaOH helps stop the expansion of these types of soils [5]. Earth is a cheap, ecological, and plenty material for construction. Indeed, it has been used widely in walls construction around the world, especially in developing countries [6]. About 30% of the world population lives in buildings made of earth. Near 50% of the population of developed countries, including most of the rural population, and at least 20% of urban and marginal population live in buildings where earth was used for its construction [7].

Manufacture of ceramic pieces for masonry represents a very important economical activity in some towns of Mexico and other developing countries. These pieces are preferred because of their cultural reasons, accessibility, and long history. Indeed they have been used since 4000 years ago in Egypt and they represent the first materials manufactured for buildings [8]. However, the low quality control of manufacturing of these pieces leads to strength variations, dimensions, and density. Moreover, because of its production environmental problems emerge such as a high-energy consumption as well as high emissions of carbon dioxide [9], thus causing damage to the public health [10]. This is so because wood, recycled automobile oil, coke, heavy oil, used tires, garbage, and plastics [11] are used as fuels for its production.

The study of different materials for the fabrication of pieces to substitute bricks of burned clay has been the aim of many researchers worried about the environment, the use of natural resources, and the recycling of industrial trashes. Red clay is a trash subproduct from the aluminum extraction. In this respect, there have been efforts for producing these bricks with fly ashes and a small percentage of CaOH. These pieces were tested by accelerated abrasion and considered ideal for its use as low-cost material for shelters [12].

Bricks made of fly ashes, CaOH, and calcium sulfide are one of the best alternatives for bricks of conventional burned clay. Comparative results indicate that the former are lighter in weight, last in aggressive environments, and have enough strength to be used in the construction of buildings [13].

Compressive strength increases 2.5 times when the percentage of cement is doubled from 6 to 12% in compressed earth-cement blocks with very sandy soils. The rate of humidity absorption depends greatly on cement content. Pores size diminishes with the increase of cement content in the block [14].

Since fifty years ago, the introduction of blocks made of compressed earth was seen as an important step. These blocks are made via compression of a humid mixture of earth (90–95%) and cement (5–10%), thus forming strong and dense blocks used for walls. While their properties are well known with respect to their characteristics of initial performance, there has been little research about their durability in the long term and the deterioration due to long exposition of environmental factors [15].

Achenza and Fenu [16] reported bricks with adobe stabilized with vegetal fibers and a composite of natural polymers. It seems that the latter modified the porosity and apparent density of the bricks and improved their behavior under water action and their compressive strength too.

Soil compaction produces an increase in resistance and decreased deformability. This process is obtained with suitable techniques applied on the soil, which improves the dry specific weight decreasing its empty spaces. Therefore, there are two main factors that determine the best density of soil material: moisture and the specific energy applied.

The specific energy of soil compaction is the compaction effort applied to the soil per unit volume and is determined using the weight, height of drop, and number of blows of a hammer to compact a volume of soil placed in layers into a mold. Therefore, Proctor found a moisture entitled "optimum" that produces the maximum dry weight under a given specific compaction energy [17].

3. Tests and Experimental Methods

3.1. Geotechnical Characterization. Geotechnical characterization of the expansive soil under study was made such as gradation test, according to ASTM D 422 standard [18]. This was done to know the grain size distribution and the proportion of sizes of its constitutive particles. Then, following the ASTM 4318 standard [19], the liquid and plastic limits were determined, as well as the shrinkage limit [20]. With this information, the soil was classified by the Unified Soil Classification System (USCS) [21]. Its specific weight and specific gravity were obtained following the ASTM D 854 standard [22].

3.2. Stabilization of Soil with CaOH. For stabilization of expansive clay, three different doses of CaOH, namely, 6, 8, and 10 percent of its dry weight, were aggregated to each sample. For each dose, the plasticity limits were obtained. The aim was to find the optimal CaOH quantity for abating volumetric changes.

3.3. Application of Compaction Energies. The compacting procedure for the stabilized soil was compaction by layers with a weight falling from a controlled height (Proctor compaction procedure). The compaction energies per cubic meter were Proctor standard (600 kN-m) and modified

Proctor (2700 kN-m), following the procedures ASTM D 698 [23] and D 1557 [24], respectively. Then, higher compaction energy (4000 kN-m) was applied. Results of these tests were the determination of the maximum dried density and the optimum moisture. This procedure is supposed to increase soil density. It should be pointed out that the modified soils tests specimens had the optimal amount of CaOH, previously determined.

3.4. Unconfined Compressive Strength. Test specimens of modified soils were subjected to unconfined compression [25] at different ages (7, 14, 30, and 60 days) and the compaction energies mentioned above. This was done to define the best behavior and strength.

3.5. Fabrication of the Brick Ceramic Material. Once the dose and compaction energy were settled, bricks of 19 cm long, 10 cm width, and 5 cm height were made. Then, they were subjected to tests for determining the break modulus and the strength to first fissure [26] for comparison with commercial bricks.

4. Results

4.1. Geotechnical Properties of Soil. By gradation analysis, via dry and humid, it was determined that the soil was a material with fines, since 94.8% of its particles went through a sieve 200 (0.074 mm). The liquid limit was 70.21% and the plastic limit was 27.56%; thus the plastic index was 42.64%. From these results, the soil can be classified as high compressibility clay (CH) according to the Unified Soil Classification System (USCS), [21]. The volumetric shrinkage limit was 8.68%, specific weight of 15.68 kN/m^3, and specific gravity of soil as 2.52. From the gradation via humid analysis, the percentage of particles less than 0.002 mm was 19.5%. With this data and the plasticity index, the activity index of the clay was determined as 4.5. Using the activity criteria the soil has a highly expansive potential [2].

4.2. Soil Stabilized with CaOH. Several test specimens of soil added with CaOH with different percentages in dry weight were prepared. Plasticity limits versus percentages of CaOH are shown in Figure 1. In this figure it can be observed that the plasticity limits properties are stabilized starting with 8% CaOH. Indeed, at that percentage there is little or nil variation of the liquid limit and the plastic index, even increasing the CaOH content. The natural soil corresponds to the 0% of CaOH. Moreover, the soil classification changes from CH (high compressibility clay) to ML (lime of low plasticity); thus, it has properties of a low plasticity soil, that is, little or nil volumetric change.

4.3. Application of Compaction Energies. The optimum quantity of CaOH placed in the soil composite was determined by its plasticity properties and was 8% (Figure 1). To include a broad range of energies, first this study includes two energies from two common assays of soils compaction, 600 (kN-m)/m^3 at Proctor standard and 2700 (kN-m)/m^3 at Proctor

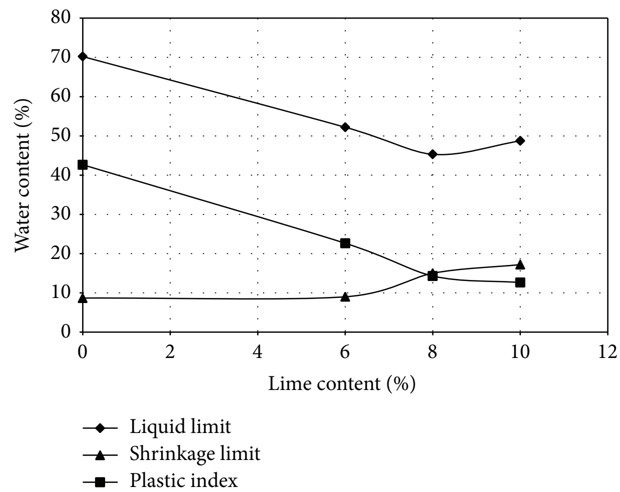

Figure 1: Atterberg limits versus lime content.

modified, and proposes a third higher energy value of 4000 (kN-m)/m^3. After applying these three energies, we observe that the best dried density of the material corresponded to the Proctor standard energy. Then with the objective of identifying the nearest energy value, the following tests were performed between values of Proctor standard and Proctor modified energies. These were 1500, 1800, 2100, and 2400 (kN-m)/m^3. Values for maximum dry density and optimum moisture content for the above conditions are shown in Table 1.

When the energy compaction of the soil increases from 600 to 2100 (kN-m)/m^3, the density increases and the optimum moisture content decreases due to compression of the soil (Table 1). Then, the next increment of the compaction energy (2400 (kN-m)/m^3) causes an increase in density and a sudden increase in moisture, which is likely due to dispersion of lumps of the soil which generates more smaller soil grains and therefore more contact areas surrounded by water which helps accommodate the soil. This energy causes a small final increase in its density. After 2400 (kN-m)/m^3, the density tends to decrease probably due to increasing dispersion of soil aggregates into discrete units by mechanical means (increasing application of energy) [17]. Therefore additional soil dispersions generate increase of water content. This caused a poor compaction of the material (low density values) because water cannot move instantaneously under the compacting hammer blows [17].

Therefore two optimal compaction energies can be considered with respect to the variation of optimum moisture, the first when the optimal humidity reaches its smallest value and the second when it increases, after reaching its lowest value.

4.4. Strength to Unconfined Compression. Stabilized-soils tests specimens were prepared and subjected to unconfined compression, following the ASTM D 2166 standard [25]. Tests specimens were subjected to specific compaction energies of 600 (Proctor standard), 1500, 1800, 2100, 2400, 2700

Table 1: Compaction properties and unconfined compressive strength at different ages.

Energy/m^3 (kN-m)/m^3	Compaction data		Unconfined compressive strength (MPa)			
	Optimum moisture content (%)	Maximum dry density (kN/m^3)	7 days	14 days	30 days	60 days
600	35.00	12.74	0.78	0.97	1.06	1.41
1500	33.30	14.70	1.32	2.01	2.71	3.57
1800	31.53	15.09	1.44	2.29	3.06	4.08
2100	31.40	15.29	1.42	2.35	3.20	4.25
2400	34.20	15.39	1.63	2.62	3.57	4.74
2700	38.20	12.25	0.49	0.40	0.42	0.50
4000	37.82	12.25	0.45	0.37	0.40	0.48

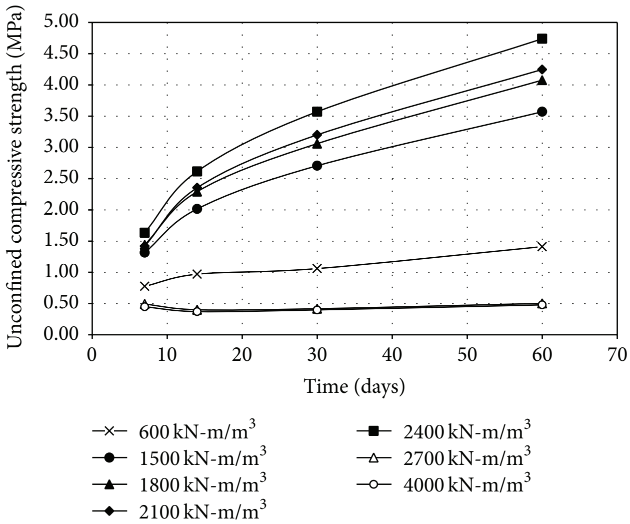

Figure 2: Composite strength for different specific compaction energies and ages.

(Proctor modified), and 4000 (kN-m)/m^3. Results are plotted in Figure 2. Figure 2 shows that the increase in density causes increases in resistance.

From Figure 2, the best strengths were obtained with the two optimal compaction energies considered (2100 and 2400 (kN-m)/m^3), the first when the optimal humidity reaches its smallest value and the second when it increases, respectively, after reaching its lowest value. This work applied the compaction effort value when the optimal humidity reaches its smallest value, 2100 (kN-m)/m^3, to obtain the best dry density of the clay composite with 8% of CaOH; this is because it is more accurate to find the smallest value of moisture in similar experiments.

4.5. Rupture Stress and Fracture Stress of the Brick Ceramic Material. To determine these values, test specimens were prepared with dimensions: 19 cm long, 10 cm width, and 5 cm height, with ages of 7, 14, 30, and 60 days, and tested according to the ASTM C67 standard [26]. Results are displayed in Table 2.

Table 2: Rupture stress and fracture stress of the proposed brick and some commercial products.

Material	Rupture stress (MPa)	Fracture stress (MPa)
Proposed brick (7 days)	0.09	1.56
Proposed brick (14 days)	0.16	2.51
Proposed brick (30 days)	0.31	3.33
Proposed brick (60 days)	0.37	3.81
Burned clay brick	0.45	3.08
Block (cement)	0.20	5.91
“Sillar”	0.01	2.38
Adobe	0.16	1.32

From Table 2, it can be observed that the best results for the proposed brick under study were obtained at 60 days. These were compared with commercial pieces for masonry, tested under the same norm. Moreover, it can be said that the proposed brick overcame the strength of burned clay brick, “sillar,” and adobe, close to the maximum fracture stress corresponding to the brick. The “sillar” is a regional brick for construction. This is a cut material extracted from sedimentary rocks as shale.

5. Conclusions

With trash expansive clay, a brick with CaOH with optimal-controlled density could be obtained. The amount of CaOH to avoid volumetric changes on this type of soils was 8%.

We conclude that in expansive soils treated with lime two optimal compaction energies can be considered with respect to the variation of a determined optimum moisture: the first when the optimal humidity reaches its smallest value and the second when it increases, after reaching its lowest value. This probably occurs due to the continuous increase in compaction energy that causes the soil particles and humidity to achieve their best accommodation: first with intact soil particles (lumps) and then with disintegrated particles of soil, respectively. Higher compaction energy values do not improve density. The increase in density causes increases in resistance. This work applied the compaction effort value when the optimal humidity reaches its smallest value to obtain the best dry density.

The proposed sustainable brick made of construction trash soil has a maximum controlled density and better mechanical behavior when compared to another commercial masonry pieces around the region (burned clay brick, "sillar," and adobe). In addition the mechanical properties of the composite increase with time.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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