Civil Engineering and Architecture 10(7): 2858-2865, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100706

Mechanical Properties of an Earth Block Compressed with Cementitious Material

Haidee Yulady Jaramillo[1], Sir Alexci Suárez Castrillón[2], July Andrea Gomez Camperos[3,*]

[1]Department of Civil Engineering, Faculty of Engineering, University Francisco de Paula Santander Sectional Ocaña, Research Group on New Technologies, Sustainability and Innovation (GINSTI), Ocaña, Norte de Santander, Colombia
[2]Department of Systems Engineering, Faculty of Engineering, Universidad Francisco de Paula Santander Seccional Ocaña, Grupo de Investigación en Ciencias y Tecnología (GRUCITE), Ocaña, Norte de Santander, Colombia
[3]Department of Mechanical Engineering, Faculty of Engineering, University Francisco de Paula Santander Sectional Ocaña, Research Group on New Technologies, Sustainability and Innovation (GINSTI), Ocaña, Norte de Santander, Colombia

Received August 11, 2022; Revised September 13, 2022; Accepted October 23, 2022

Cite This Paper in the Following Citation Styles

(a): *[1] Haidee Yulady Jaramillo, Sir Alexci Suárez Castrillón, July Andrea Gomez Camperos , "Mechanical Properties of an Earth Block Compressed with Cementitious Material," Civil Engineering and Architecture, Vol. 10, No. 7, pp. 2858 - 2865, 2022. DOI: 10.13189/cea.2022.100706.*

(b): *Haidee Yulady Jaramillo, Sir Alexci Suárez Castrillón, July Andrea Gomez Camperos (2022). Mechanical Properties of an Earth Block Compressed with Cementitious Material. Civil Engineering and Architecture, 10(7), 2858 - 2865. DOI: 10.13189/cea.2022.100706.*

Abstract The main objective of this project is to evaluate the behavior of the soil of the municipality of Ocaña Norte de Santander to manufacture Compressed Earth Blocks (CEB). This project seeks alternative materials that allow self-building for the most vulnerable communities. This research seeks to value and strengthen sustainable construction in the municipality. This allows for minimizing the use of Portland cement, which, due to the high energy consumption and CO_2 emissions during the construction of homes, is one of the main causes of the high carbon emissions the construction activity produces. As a result, experimental and quantitative research was developed, in which characterization of the different sector materials was made. Then, the design of mixtures and failure time were determined, and 10×15×30 cm samples were elaborated. Bricks elaborated with the different mixtures and acquired strength higher than 3.0 MPa at 28 days after manufacture, allowing compliance with the Colombian technical standard (NTC-5324) standard. Finally, the bricks obtained met the mechanical characteristics suitable for use as non-structural masonry.

Keywords Self-Construction, Compressed Earth Blocks, Sustainable Construction, Soil

1. Introduction

The construction sector is the first promoter of brick manufacturing in any of its existing varieties, implemented between the years 10,000 and 8,000 BC to protect the human being and create monuments that have endured in history. Likewise, the construction sector is responsible for generating a negative environmental impact with carbon emissions of 30% worldwide, emissions of other gases and particulate matter, and a deterioration of the landscape and underground and surface water bodies.

In addition, this sector is responsible for the consumption of 40% of the raw materials in the world; equivalent to 3 billion tons per year, 17% of drinking water, 70% of total timber resources, 10% of arable land, 20% of total world energy consumed during the construction process. Processing of materials and demolition of construction sites and consuming almost exclusively non-renewable stone materials has become, in most countries, the main generator of greenhouse gases; with emissions that by 2004 reached 1.8 billion metric tons according to the Intergovernmental Panel on Climate Change and that could reach 15.6 billion metric tons until 2030, models followed by [1,2].

One of the most common construction elements is ceramic brick. In Colombia, about 1,500 to 2,000 kilns produce an estimated 350,000 tons of bricks per month with an average consumption of 0.07 tons of coal per ton of bricks produced, which emit: nitrogen oxides, sulfur oxides, carbon dioxide, and particulate matter [3], which are already linked to climate problems in cities, such as Medellín and Bogotá, where air pollution has lasted two days, causing the population to use face masks and reduce going outdoors [4].

Particularly in the city of Ocaña, around 30 pools are active, distributed in different parts of the city, which produce ~1,027.600 products/month. These pools use rudimentary and manual methods for the manufacture of masonry. Products derived from clay, such as tiles and bricks, are manufactured in traditional ovens, which generate several gases that cause the greenhouse effect, causing a negative footprint on air quality, which in turn generates a drastic climate change.

Faced with the environmental problems generated by this industry, it is fundamental to start considering alternative methods for the production of bricks, the compressed earth blocks "BTC" with cement [5,6], which are a sustainable alternative because their manufacture does not emit gases that are harmful to the environment. However, they have a significant shortcoming, and that is that after their manufacture and use in homes or other types of infrastructure, in which they can be used according to their technical sheet. It is susceptible to humidity because it is not petrified, that is, when it comes into contact with water due to natural events or other types of daily work, it suffers processes of loss of its physical-mechanical properties when it begins to crumble and lose structural strength.

Earth or raw mud has been used to build houses in the world's most influential cultures. These are located in places such as Egypt, Iran, China, and Mesoamerica since the applied construction techniques were facilitated with this material, since it was abundant, easily obtained, and could be handled at the foot of any construction site [7,8].

Different constructions have been preserved over the centuries, allowing us to verify that various construction techniques with earth have emerged in almost all past civilizations. These techniques spread through invasions and colonization, common in the history of humanity. The native techniques joined the techniques brought by foreigners and, with various combinations, were adapted and organized in the most appropriate ways for construction. The techniques present similarities from one region to another, but each has peculiarities and nomenclature that often confuses even the most studious [9,10].

It is estimated that about 30% of the world population, about 1,500 million people, currently live in constructions on land; In the case of undeveloped countries, close to 50% of the rural population and 20% of the urban population lives in earthen buildings. In countries like Peru, 60% of the houses are made of adobe or rammed earth. In India, this figure rises to 73%, equivalent to 67 million houses were 374 by million people [11,12].

Among the construction procedures with earth, the Compressed Earth Block (CTB) stands out, so-called because semi-mechanized or mechanized machinery is used to produce them, and at the same time, substances or materials are added that improve their original characteristics [13]. Another procedure is called Tapial, which consists of tamping the soil into a falsework or formwork to construct walls. A standard procedure in Latin America and the most rudimentary of all is the so-called Bahareque, based on embedding a rod structure. It should be noted that there are other procedures that vary according to each place's local conditions [14].

Due to the knowledge acquired over time about construction with earth, innovative dynamics have been set in motion to achieve dissemination through virtual communication on the Internet. The knowledge generated in research and other experiences, previously limited to scholars and builders, is now more and better disseminated. Portals, virtual networks, social networks, and email have become an excellent ally for the advancement of construction on the land since they allow researchers and other professionals to be found and contacted, to change information and knowledge in a timeless world, without borders or distances, unimaginable in past generations

As a sustainable construction material, the earth is the most important and abundant in most regions of the world [15]. This is frequently obtained on-site when the foundations are excavated. Earth as a material has been given different names. For example, mud is a mixture of clay, silt (very fine sand), and sand, with larger aggregates of gravel and gravel. The term mud or adobe blocks is generally used when talking about clay earth blocks made by hand. When talking about compressed blocks, the term soil blocks are used. When they are extruded in a brick factory and are not fired, they use the term raw brick [16].

Some of the advantages offered of using earth as a construction material are:

- Low visual impact, easy integration of constructions in the landscape.
- Local material, from excavations and conditioning, works, avoiding transport costs.
- Recyclable character of the material, since it is quickly reduced to its original state after the demolition of the building, without producing industrial waste.
- The material production process is clean and requires low energy consumption.
- The material has good characteristics as a thermal insulator compared to other frequently used construction materials [17].

In the event that the land to be used does not meet the appropriate characteristics for the construction, these can be achieved with the use of stabilizers. This process uses a physical or chemical method that allows land to respond satisfactorily to the requirements imposed to be used as a construction material [18].

2. Materials and Methods

This research aims to manufacture compressed earth blocks (CTB) with the sandy clay soil of the municipality of Ocaña Norte de Santander. For the development of the research, an experimental methodology was chosen, and the variables identified are the type of soil and the cementing agent used.

2.1. Research Stages

2.1.1. Location

Initially, it was necessary to establish the area's location to obtain the samples and that it would be a possible point for the extraction of soil for the elaboration of the blocks. In this sense, a sector to the northeast of the city was chosen, as shown in Figure 1, where a wide extension of material in sandy clay can be seen.

Source: Authors

Figure 1. Location of the study area

2.1.2. Material Characterization

In order to establish the characteristics of the study soil, the tests mentioned in Table 1 were carried out:

Table 1. Description of the tests developed

Standard	Description
I.N.V.E-125	Determination of the liquid limit of soils
I.N.V.E-126	Plastic limit and plasticity index of soils
I.N.V.E-123	Granulometric analysis of soils by sieving
I.N.V.E-141	Moisture ratio – dry unit weight in soils (Normal compaction test)
NTC 4017	Methods for sampling and testing masonry units and other clay products compressive strength

2.1.3. CTB Processing

Once the material was characterized, a percentage of cementitious material was established, and a combination of lime and cement was added to the soil, mixing it with the optimum humidity to achieve maximum compaction. The machine used to elaborate the compressed earth blocks consisted of a cimbarra, as shown in Figure 2. After the manufacturing process, special care must be taken with the curing process for the first 3 to 7 days, accommodating the blocks in a form such that ventilation is achieved between them, as shown in Figure 3.

Source: Authors

Figure 2. Manufacture of CTB in the cimbarra

Source: Authors

Figure 3. CTB curing and accommodation process

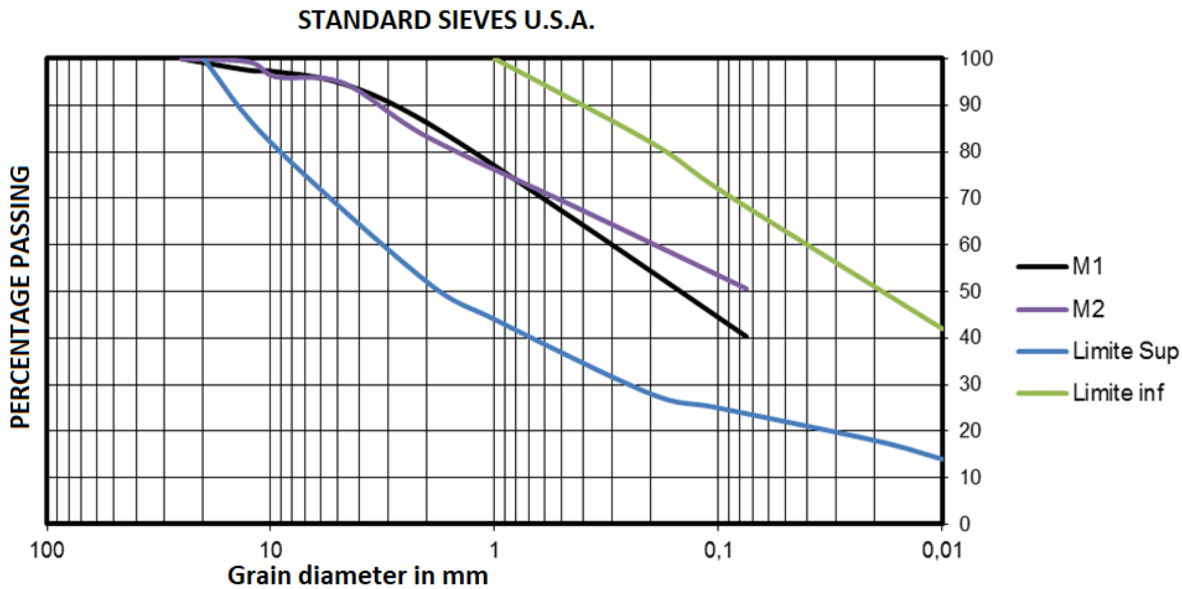

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Figure 4. Particle size curves

2.1.4. Resistance Tests

After the curing process, the age of 28 days, individual tests were carried out on the CTB to establish the compressive strength, by the provisions of NTC-4017 "Methods for sampling and testing of masonry units and other products of clay resistance to compression" and later compare it with the values established in NTC-5324 for soil-cement blocks.

3. Results and Discussion

Once the place for the exploration was identified, the collection of the different samples of the material for its respective characterization began.

3.1. Particle Size Test

The study area identified two predominant types of soil, whose granulometric distribution can be seen in Figure 4. Furthermore, in this same graph, the lower and upper limits defined in NTC-5324 for compressed earth blocks have been located, observing that the study material is suitable for elaborating the blocks.

Table 2 specifies the gravel, sand, and acceptable percentages for the analyzed samples. Although not high, the variation between both materials is considerable, and the fraction that most influences whether it is optimal or not is the percentage of fines since these directly influence the plasticity of the material.

3.2. Plasticity Limits

Identifying the materials or soils analyzed is achieved considering the plasticity limits, which will determine the group to which the soil belongs. In Table 3, is possible to observe the values of the liquid limit, plasticity limit, and plasticity index, respectively.

Concerning these values, the variation is very little. Therefore, one could generally speak of material with medium to low plasticity. Now, regarding the classification of both soils, these correspond to an OL (Low plasticity organic silt) and an SM (Low plasticity silty sand) for the samples M1 and M2.

In Figure 5, an analysis of the plasticity values is carried out concerning the ranges established by NTC-5324, and it can be seen howsample M1 remains outside the shaded area, which indicates the tolerance range. Instead, it shows M2 if it falls within these parameters.

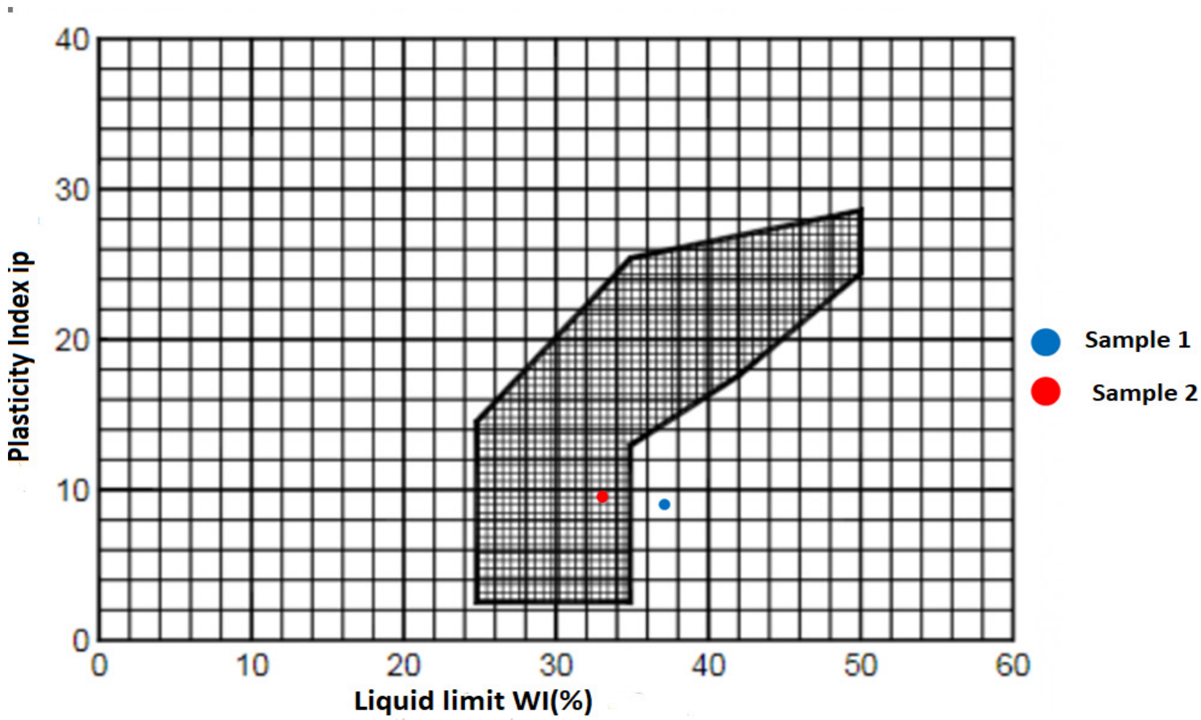
After the characterization of the materials or soils corresponding to the deposit in the study area, a percentage of the cementing agent was established, for example, a combination of lime and cement, in a proportion previously established by trial-and-error adjustments in the laboratory.

Table 2. Material percentages

Sample	% Gravel	% Sand	% Fines
M1	5.2	44.2	50.6
M2	5.4	54.2	40.3

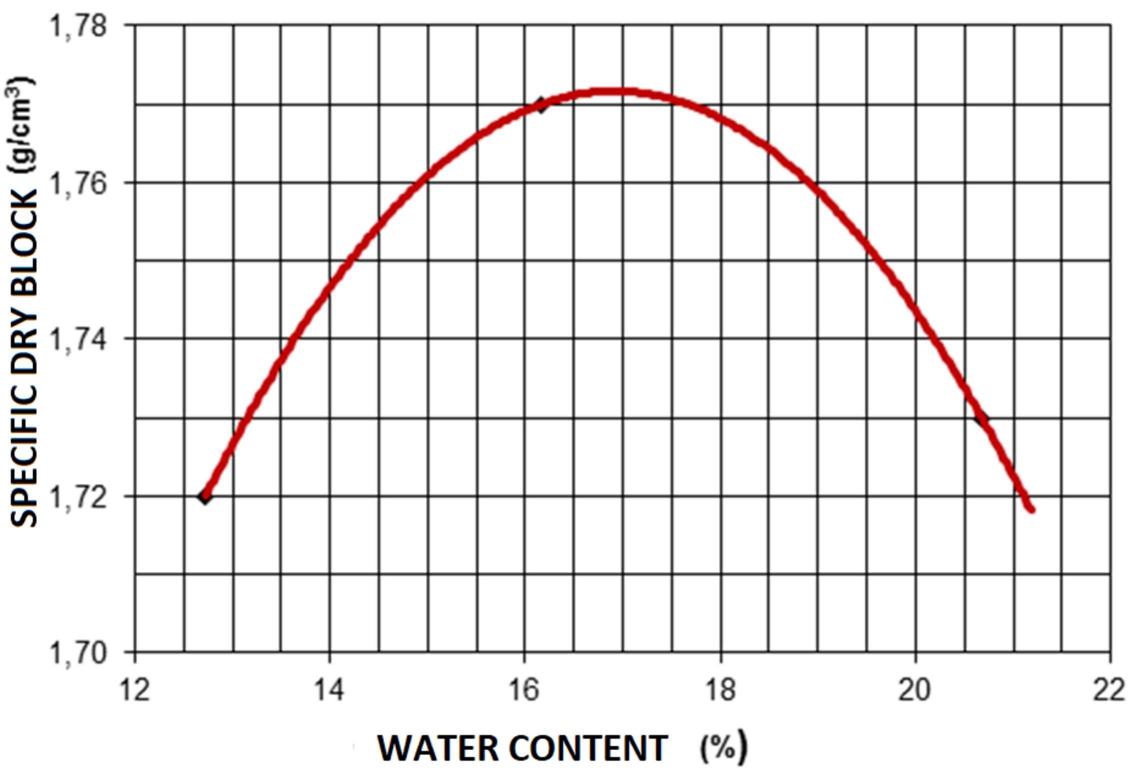
Table 3. Plasticity limits

Sample	LL (%)	LP (%)	IP (%)
M1	37.10	29.12	8.18
M2	33.62	24.92	8.70



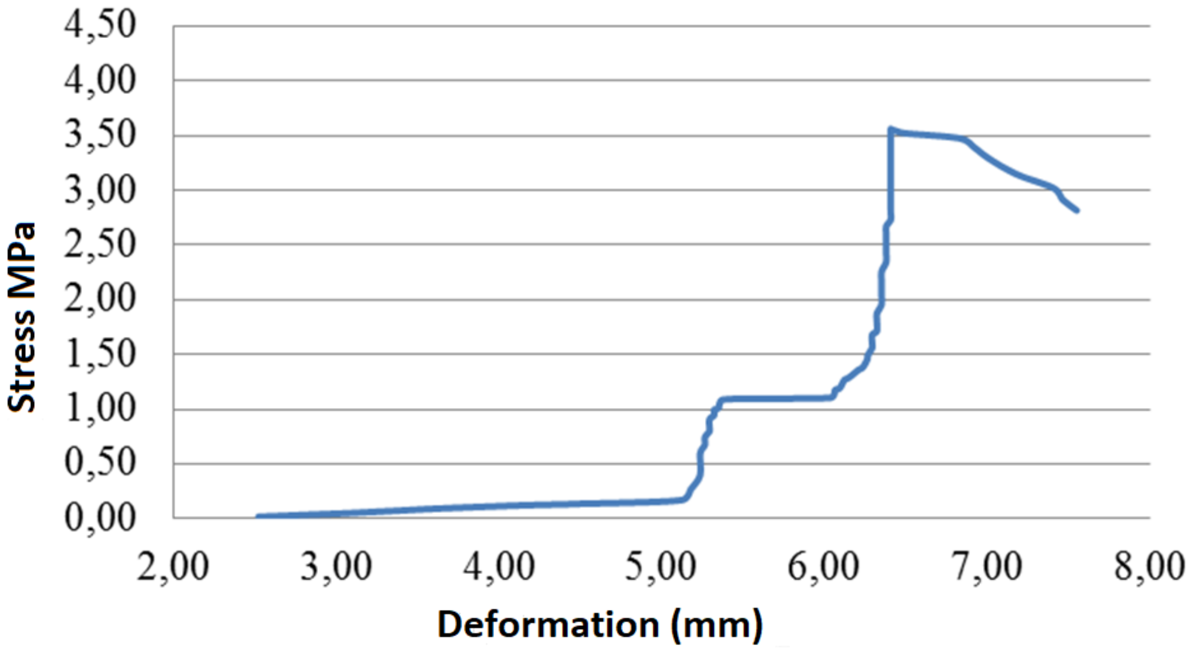
Source: Authors

Figure 5. Plasticity ranges



Source: Authors

Figure 6. Compaction curve M1



Source: Authors

Figure 8. Stress vs. Strain M1

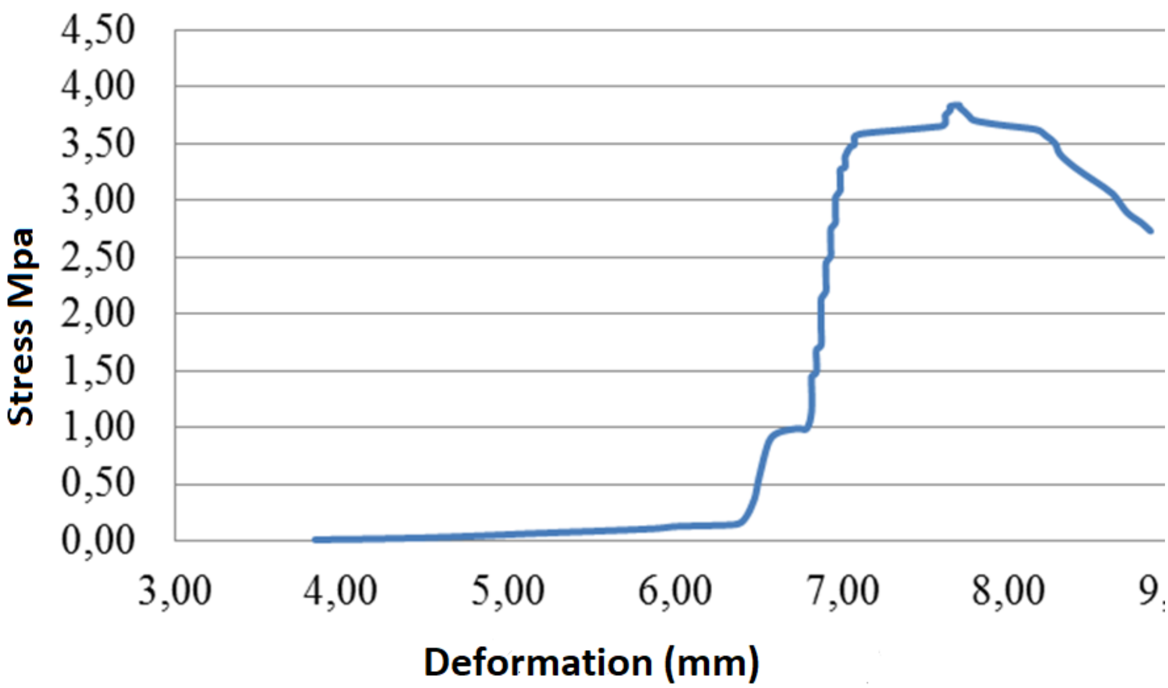


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Figure 9. Stress vs. Strain M2

3.3. Compaction Tests

Before carrying out the BTC, it is necessary to identify the optimal humidity of the material to achieve maximum compaction of the same. Figures 6 and 7 show the curves corresponding to the relationship between specific weight and moisture for samples M1 and M2.

The maximum density was 1,775gr/cm^3 and 1,792gr/cm^3, respectively, for M1 and M2. Likewise, the optimal humidity for the mixtures corresponds to 16.80% and 15.60%.

3.4. Compressive Strength

Once the optimal humidity for the elaboration of the blocks was defined, the elaboration of the CBT proceeded using the cimbarra, and after careful curing for 7 days at 28 days of age, the blocks were tested under compression, obtaining the results shown in Figures 8 and 9.

The maximum stress reached was 3.56 MPa and 3.84 MPa for M1 and M2, respectively.

4. Conclusions

With the development of this research, it has been possible to demonstrate that compressed earth blocks or CBT are a viable alternative to industrialized construction in conventional bricks. In addition, CBT constitutes a sustainable option and can also be carried out in vulnerable communities with meager costs.

From the results, it was observed that, even when the materials or soils found in the study site correspond to the same geological formation, they present differences that manage to influence the results. Initially, soil M1 has a greater number of fines and a higher percentage of liquid limit compared to soil M2. In the same way, according to the parameters established by NTC-5324 standard procedure, only sample M2 in terms of plasticity is suitable for making blocks in compressed earth.

Likewise, the compressive strength results indicate that with the same percentage of cement incorporated, the M2 sample reaches a greater effort. That said, it is possible to ensure that for the manufacture of CBT with the soil present in the study area, it is more feasible to use the M2 soil that corresponds to an SM or silty sand. However, using the other floor should not be ruled out since a higher percentage of cement can achieve greater resistance and improve its behavior.

Finally, even though CBT tends to have lower resistance than conventional bricks, this alternative has additional advantages, which are not only reflected in the cost of production but also in the considerable reduction in the environmental impact generated to constructions on land.

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