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# Soil cement brick production process: literature review

## Abstract

Soil-cement brick is one of the most common building materials for masonry construction, although it is not the oldest. As it is a product made up basically of soil and cement, it has existed in Brazil since the appearance of cement. The brick has been gaining market share due to several characteristics: ease of production, as it can be produced at the construction site itself, ease of obtaining raw material, as the soils exist in all locations, low processing costs, and easy handling. In addition, the soil-cement brick, also called ecological brick, stands out for not harming the environment like the ceramic brick that needs to be burned. Despite being a standardized product, production procedures and properties need to be updated. As an example, the soil used is very coarse which makes it difficult for the components to react. After conformation, the cure is still carried out without humidification, not obtaining adequate resistance. Furthermore, durability has been little studied. Thus, this article presents a literature review based on research in the production of soil-cement bricks. Materials and research methods used in the process of making soil-cement bricks, as well as various properties, are discussed. The most common results are grouped. The literature review showed that the production process is well defined, although it needs improvement. As for material properties, they meet the standards. However, the entire process needs more research.

**Keywords:** brick, soil-cement, residue, recycling, ceramics

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## Introduction

Civil construction has been looking for alternatives for sustainable production, mainly to reduce process costs. These include decreasing environmental pollution, reducing the amount of waste, and protecting raw materials from depletion, thus contributing to sustainability and greener approaches.

The civil construction industry is one of the segments that most contributes to economic development. However, it is estimated that this industry uses around 40% of the world's natural resources and is considered the largest source of environmental pollution.[1] Therefore, this branch of civil construction has been seeking to introduce sustainable practices and materials throughout its production chain. With social development focused on sustainability, the civil construction market, engineers, and architects are progressively paying attention to the selection of sustainable materials and observing issues such as air contamination inside the building, environmental ventilation rates, material durability, the impacts that can be caused in case of disposal and how they can be reused.[2]

For current constructions, there are at least three types of bricks: ceramics made from clay, which after processing and shaping must be burned; cement blocks, produced with sand or stone residues used in civil construction, and bricks from soil-cement, also called ecological bricks.[3–5] The production of ecological soil-cement bricks results in less damage to the environment, as it avoids the burning of raw materials and the generation of pollutants in the atmosphere, as occurs in the production of ceramic bricks.

The manufacture of Portland cement began in Brazil in 1888, with the installation of a factory on the Santo Antônio farm, located in Sorocaba-SP. Only in the 1970s, soil-cement bricks became the object of research in Brazil, especially through the Brazilian Association of Portland Cement (ABCP). Before that, there are few records of its use in the country, as in the city of Petrópolis (RJ) in 1948, with the construction of residential houses, and in Manaus (AM) in 1953, with the construction of a hospital entirely on walls of soil-cement. The good condition of these works after several years of use attest to the quality of the product and the construction technique.

One of the characteristics of the construction using the soil-cement brick is the possibility of using different types of soils. In addition, the equipment used is simple and low-cost, enabling the production of the brick on the job site. This reduces transportation, energy, labor, and tax costs. In addition to these advantages, the soil-cement brick also favors from an ecological point of view, as it does not undergo the burning process, in which large amounts of wood or fuel oil are consumed, in contrast to the bricks produced in ceramics and potteries.[6]

According to Siqueira,[7] the preparation, transportation, and handling of the soil at the construction site require about 1% of the energy needed for production. The soil-cement brick reappears not only as a sustainable solution for buildings but also as a solution for the use of various residues, including them in its formulation. Several groups such as the Association of Entrepreneurs in Sustainable Solutions (AESS) and the National Association of the Ecological Brick Industry (ANITECO) have been researching on the soil-cement brick with the addition of residues to produce the so-called ecological brick, as shown in Figure 1.


**Figure 1** Soil-cement brick.

Researchers show that the soil-cement brick has numerous advantages, such as the ease of installation of piping for hydraulic services, since the bricks have holes that overlap in the settlement and form ducts through which the wires and hydraulic ducts pass, reducing the consumption of mortar for laying and smoothing, and have the advantage of offering thermal and acoustic comfort superior to that of conventional constructions.[8,9]

The soil-cement brick can be molded by manual or hydraulic presses, which guarantees it mechanical resistance equal or superior to conventional ceramic bricks and concrete blocks.[10] Hydraulic presses are better than manual ones, as there is the possibility of automation, in addition to regulating the conformation pressure.

The brick must have sharp edges and must not present cracks, fractures, or other defects that could compromise the settlement, strength, and durability of the masonry. The brick must have the external shape of a rectangular parallelepiped. In addition, the soil-cement brick stands out for its composition that is, it is mainly formulated by soil, as well as enabling the replacement of part of this raw material by residues. Thus, it is still possible to highlight all the advantages of the soil-cement brick over the traditional construction system: reduction in the thickness of the coatings, savings in forms, rationalization of electrical and hydraulic installations, and reduction in the waste of materials.[11,12]

The soil-cement brick, despite being used for a long time, has some properties as process parameters, which are still poorly studied. Thus, this work aims to present what exists in research regarding the manufacturing process of the soil-cement brick, to encourage researchers to direct studies for the production of better-quality products.[13]

## Materials and methods

### Soil

**Clays, sand, and silt:** In the composition of the soil-cement brick, the soil is the material that enters in the highest percentage, and it must be selected in a way that allows the lowest possible consumption of cement to be used. The soil is made up of clay, silt, and sand, and may also contain contaminants such as limestone, feldspar, and others.[14,15] There is a f necessary to know the clay mineral that constitutes the clay fraction, as the characteristics and properties of the clay mineral will define the final properties of the brick. Clays that have montmorillonite-type clay minerals (smectites) in their composition are inadvisable, as they are highly expansive and need a lot of cement for stabilization, in addition to promoting cracks.[16,17] Additionally, soils that contain organic matter should be avoided, as this component influences both cement hydration and soil stabilization, favoring a drastic reduction in durability over time. However, the percentage of organic matter present in clays has been little studied. The formulation of the soil-cement brick is inadequate with soils with a high percentage of clay (> 30%) due to the great absorption of water by these particles, which causes high shrinkage in the drying process, leading to the appearance of cracks. However, small percentages of clay are beneficial to ensure cohesion in the fresh molded blocks.[16] Due to the geological formation of all soils from rocks, practically all of them have sand in their composition, with higher or lower content.

Sand are silicates ($SiO_2$) coming from the erosion of rocks, characterized by being inert, with a high specific mass, which favors greater stability and final resistance of the soil-cement brick. Sand is not added as an isolated raw material, it is already mixed with clayey soils.[17] In the sandy fraction, it is found a more adequate particle size distribution that provides a high apparent specific mass in the pressing of the mixture, responsible for the mechanical properties, and that guarantees a much higher mechanical resistance than soils containing basically clay.[18] Yet, soils with a large predominance of sand require more waiting time for them to acquire sufficient strength to ensure the integrity of the brick.[19,20]

Table 1 shows the cement-brick soil formulations proposed by authors from different communities. It is noticed that sand must be present in the soil composition. However, the clay material, as well as the silt, are fundamental to obtain the conformation by pressing, as the clay will provide the plasticity, and the silt, besides having a high specific area, favors the conditioning. The soil can be made up of clay or a mixture of clays, and it may contain sand or even a phyllite.[18–20] The data collected in Table 1 were plotted in Figure 2 in a ternary diagram, to propose a formulation. Thus, the proposal can be defined as follows: silt (15-35%), sand (50-70%), and clay (10-20%).

**Table 1** Soil Composition (%)

| Clay | Silt | Sand | Others | References |
|---|---|---|---|---|
| <15.0 | <15.0 | <50.0 | < 35.0 | Siqueira[7] |
| <40.0 | - | 29 | 31 | Oti[21] |
| 44 | 5 | 47,0 | 4 | Danso[22] |
| 21.8 | 20.8 | 57.7 | - | Saari[11] |
| 22.4 | 28.4 | 49.2 | - | Rodrigues[23] |
| 8.8 | 59.2 | 32 | - | Nuntaporn[24] |
| 52 | 16 | 32 | - | Vilela[10] |
| 22.5 -32.0 | 38.5-40 | 28.0-37,0 | 2 | Quedraogo[25] |
| 53 | 44 | 3 | - | Akynyemi[26] |
| 55 | 20 | 30 | - | Hany[27] |

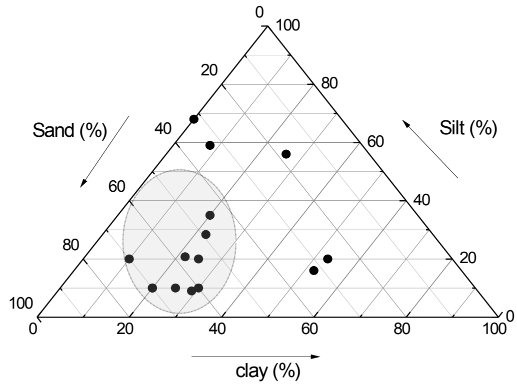


**Figure 2** Ternary diagram of the ideal composition of a soil-cement brick.

### Soil properties

**Particle size analysis**: according to ABCP (1985)[28] and NBR 10833,[29] for the manufacture of soil-cement bricks, the most suitable soils have the following characteristics: 100% passes through the 4.8 mm sieve and 10% to 50% of the sample passes through the 0.075 mm sieve. However, it seems that the beneficiation process has not evolved, and the soil is quite coarse. It is recommended to use more advanced processing processes such as grinding in hammer mills, whose raw material passes 100% through the 0.298 mm to reduce the action of impurities, as is already customary in the manufacture of ceramic tile via dry milling.

Then, the soil must be mixed with the cement and moistened by means of sprinklers or, if automated, rotary granulators to ensure the ideal pressing granulometry.

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**Mineralogical composition**:

According to Table 2, the clayey soils used in the production of soil-cement bricks are constituted by the clay minerals kaolinite, illite; rarely by smectite or montmorillonite, and may contain accessories such as mica, calcite, quartz, and feldspar. As already discussed by Lei,[30] the use of clays containing montmorillonite should be avoided because, in contact with water, there is an increase in volume, which can cause cracks, in addition to presenting great differential shrinkage. Additionally, in his studies of incorporation of montmorillonite in a cementitious matrix, observed a drastic drop in workability due to its water absorption capacity.

**Table 2** Mineralogical composition of the soil

| S | K | I | G | V | M | C | F | Q | References |
|---|---|---|---|---|---|---|---|---|---|
| | X | X | | | X | | X | X | Amaral[31] |
| - | X | - | - | - | - | - | - | X | Rodrigues[27] |
| - | X | X | - | - | X | X | X | - | Danso[25] |
| - | - | - | - | - | - | - | - | - | Nuntaporn[22] |
| - | X | - | - | - | - | - | - | X | Vilela[10] |
| | X | x | | | X | X | X | X | Quedraogo[23] |

S, smectite; K, kaolinite; I, illite; G, goethite; V, vermiculite; M, mica; L, limestone; F, feldspar; Q, quartz.

**Plasticity and organic matter index**:

In Table 3 presents the results of liquidity limit (LL) and plasticity index (PI) of soils used in the production of soil-cement bricks. Data were plotted on a plasticity chart, as shown in.[32]

**Table 3** Technological properties

| LL (%) | PI (%) | OM (%) | References |
|---|---|---|---|
| 27.6 | 15.6 | 0.87 | Akinyemi[24] |
| 31 | 9,9 | - | Vilela[10] |
| < 45 | < 18 | - | ABCP[28] |
| 27.9 | 9.5 | - | Rodrigues[27] |
| 27.7 | 9.4 | - | Kongkajun[9] |
| 20.8 | 8.2 | - | Danso[25] |
| < 45 | - | - | CEPED[17] |
| 34 | 15-21 | - | Quedraogo[23] |
| 41.5 | 14.3 | - | Jose[36] |

LL, liquidity limit; PI, plasticity index; OM, organic matter

ABCP[28] and NBR 10833[29] recommend that the liquidity limit (LL) be less than 45% and that the plasticity index (PI) be less than 18%, which were determined according to the NBR 6459 standards,[33] NBR 7180[34] and ASTM D4318.[35] It can be concluded that the soils used for the production of soil-cement bricks can be classified into clays of low and medium plasticity in which kaolinite and illite clay minerals predominate. The results can range between 20% and 45% for (LL) and 10% to 20% for (LP). Concerning organic matter, Hany[26] recommends less than 1%. However, it was observed that there is a need for research in this area since organic matter is harmful to components containing cement.

## Cement

In the literature, there is a diversity of cement types used in the production of soil-cement bricks, ranging from common Portland cement (CPI) to high initial strength cement (HIS). They can be resistant to sulfates or low heat of hydration.[20,37] Regarding the ideal percentage of cement for the production of soil-cement brick, Nagaraj[38] recommends the range of 6% to 10% as being sufficient to ensure the necessary strength and durability. Content higher than 15% of cement makes the production economically unfeasible.

Other researchers recommend that the cement content in a formulation consisting primarily of sand ranges from 5% to 9%.[39,40] Milani and Freire[41] observed that the sandy soil was considered the ideal in their study to compose and stabilize the soil-cement mixture, as it presented an uneven particle size, and presented a better interaction between the soil and the binder, in addition to having enough clay + silt to ensure greater plasticity of the mixture. According to Moriarty et al,[42] the minimum amount of cement to be used in brick formulations for internal walls is about 5% to ensure the handling and support of the upper elements, while for external walls, the durability requirements suggest percentages of 7%, and for foundations require values of 8%. According to Table 4, the ideal percentage of cement for brick production should vary depending on the type of soil and should be between 5% and 10%. Although not reported in the literature, when molding bricks in a hydraulic press that have a device for increasing pressure, the percentage of cement can be reduced and, therefore, should be investigated.

**Table 4** Percentage (%) of cement used in the production of soil-cement brick

| Soil types | Building types | (%) Cement | References |
|---|---|---|---|
| Sandy | - | 10-May | Reddy[43] |
| sandy | - | 9-May | Sehk[39] |
| sandy | - | 12 | Milane[41] |
| sandy | - | 10 | Kasinikota[44] |
| sandy | - | 12-Aug | Bhariappanar[45] |
| sandy | | 8 | Donkor e Obonyo[46] |
| sandy | - | 10-May | Vilela[10] |
| Sandy and silty | - | 9 | Milane[41] |
| Silty | - | 10-Jul | Sehk[39] |
| clayish | - | 10-Aug | Dao[40] |
| clayish | - | 10-Jun | Nagaraj[38] |
| sandy | Inner walls | ≥ 5 | Moriarty[42] |
| sandy | Inner Walls | ≥ 7 | Moriarty[42] |
| sandy | Inner Walls | ≥ 8 | Moriarty[42] |

## Production process

### Soil and waste characterization

After collecting the soil or residue, it must be dried in an oven at (105 ± 5) ºC, disaggregated, and passed through an ABNT No. 4 sieve (4.8 mm). To carry out the chemical and mineralogical characterization, the soil must be sieved in an ABNT No. 200 mesh sieve (0.074 mm).[47] Some soil characterization tests are recommended, such as the chemical composition of the materials, which must be carried out to know the soil components. Chemical analysis can be performed by X-ray fluorescence spectroscopy (FRX). The loss to fire (LF) of the samples can be performed in an electric oven to determine the percentage of organic matter. The particle size analysis of raw materials can be determined through a series of procedures, according to the NBR 7181 standard.[48] Through particle size analysis, the percentage of soil components is determined.[20] The specific mass can be determined by the pycnometer method, while the specific surface area can be obtained by the Blaine method or similar. Some researchers recommend lifting the compaction curve to define the optimum pressing moisture, although this is just a reference since this moisture must be lower during the pressing process.[10,19]

**Production of mixtures**

According to NBR 10883,[29] the formulation is the proportion in parts by mass or volume of the components that will be used in the production of the brick, that is soil or waste and cement. The mixture must be carried out by first mixing the dry materials, normally carried out in the air, and then they are normally mixed in a concrete mixer or similar, until complete homogenization, verified by the uniform coloration. Then, the water is added through sprinklers until the mixture reaches the desired humidity. A new sieving process is recommended to better homogenize the water in the soil-cement mixture, before pressing.[47–49] Then, the mixture must pass completely through a sieve 4.8 mm to adjust the particle size.[10] In Figure 3, a suggested flow of soil-cement brick production processes is presented.

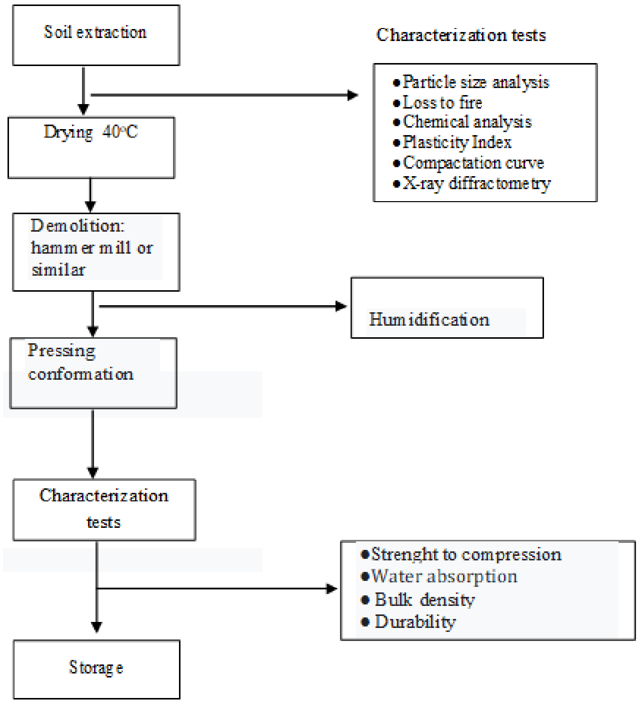


**Figure 3** Process flow for the production of soil-cement bricks.

The bricks are compacted in a manual or hydraulic press, controlling the compaction energy, with the correct control of the quantity of the material, in order to obtain bricks rigorously manufactured following what was previously established.[5,19] After curing for 7 days, the brick may be subjected to tests to characterize its mechanical resistance to compression, water absorption, bulk density, and durability.

**Compression**

According to Lei,[30] among the factors that influence the brick production process, the compaction force is the most important. The greater the compaction pressure, the smaller the amount of cement should be used and the greater the brick's strength.

Concerning to the compaction pressure factor, in most of the articles researched, the absence of this information is noted, and few investigated the influence of this parameter in their experimental analyses. In the rare articles found, the compaction pressure is mentioned briefly, where they portray its influence on the properties of the soil-cement brick, but they do not present monitoring data for this factor.

In the work by Bhairappanavar,[45] they produced 10x20x5 cm bricks, the forming pressure ranged from 2 to 4 MPa. He noted that for bricks containing 8% cement, the strength increased up to 40% by increasing the pressure from 2 to 4 MPa. This increase is due to the increase in density. The improvement in strength is due to the formation of calcium silicate C-S-H and calcium mono aluminate $C_4ASH_{12}$ due to cement hydration. Uzoegbo[50] investigated the mechanical behavior of bricks produced by varying the compaction pressures used for the production of blocks/bricks ranging between 1 MPa and 20 MPa. He noted that the pressure of 10 MPa was adopted and influenced positively the compressive strength of the brick produced.

**Humidity (%)**

The percentage of water used in compaction is determined from the compaction curve, which obtains the ideal moisture content to obtain the maximum dry density.[29,30] A study by Jimenez[51] investigated the influence of moisture in soil-cement bricks to obtain the best properties. Sandy and silty soils, with a volumetric ratio of 1:10 (cement: soil), were used for the manufacture of bricks, obtaining molding moisture contents of 19% and 22%, respectively. However, in the literature, some researchers adopt some ranges for water, from 5% to 15%. However, the optimal moisture is related to the plasticity index of the mixture, particle size composition, and, therefore, it can fluctuate.[50]

It is known that the ideal moisture content that leads to maximum dry specific mass is not necessarily the same content that achieves maximum strength. It depends on the type of soil used, where for sandy soils the maximum resistance is reached in the dry branch and, for clayey soil, in the wet branch.[49]

**Cure**

NBR12024[52] specifies that after molding, the soil-cement brick specimens must be placed in a humid chamber at a temperature of (23 ± 2) °C and relative humidity up to 95%. Nevertheless, manufacturers do not have a chamber, and curing takes place in closed sheds. The norm also specifies that for exclusive soil-cement dosing purposes, the curing period must be at least seven days. Even so, other curing ages can be considered for control.

According to Parsons,[53] the use of cement is a common method of chemical stabilization of clay soils and has been extensively used worldwide. The soil-cement is a mixture of the selected soil, the cement, and the water which are mixed and compacted in a specific dry density. The water causes the cement hydration and therefore the calcium-silicate-hydrate (C-S-H) and the calcium-aluminate-hydrate (C-A-H) are formed. During the cement hydration, the excess calcium hydroxide (CaOH) is released. The cement hydration products will be formed until the unreacted cement particles and free water remain in the mixture. The hydration of the cementitious soil in the first seven days after molding is essential to guarantee the cement's strength. They stated that the minimum period to complete the soil-cement interaction ranged from 3 to 7 days, reaching 15 days in high plasticity soils. In the case of fast-drying, a reduction in strength of approximately 40% can occur, which makes curing an indispensable process.

Although any type of soil can theoretically be stabilized with cement, it is considered as suitable as all soil that can be treated with an amount of cement economically competitive compared to other stabilizers. In this aspect, the soils granules stand out much more efficiently than clayey ones, reaching more resistance high, with lower cement contents. The type of clay mineral present in the soil is also of important importance in stabilization with cement. In this aspect, Basso[54] studying the behavior of several clay minerals with

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cement, found that: a) kaolinitic and ilitic soils are more susceptible to stabilization with cement than soils that selected large quantities of expansive clay minerals; b) very clayey soils are difficult to be stabilized, requiring large amounts of cement, however, in some situations, preliminary lime treatment and later addition of cement can lead to acceptable results; and c) always reduction in the plasticity index and increase in the limit of contraction when mixing cement to the ground. Poor curing can also influence the final product, and the soil-cement surfaces may present a crumbling surface, making them vulnerable to bad weather and any more rigorous action. An efficient curing process consists of a few daily soaks, for a minimum period of seven days. This process keeps the bricks moist, ensuring the absence of cracks and the desired final quality. An important factor to consider is the storage of parts. They should, after pressing and demolding, be stacked on a flat floor in the shade or a covered and protected place.

Once cured, the soil-cement brick or block has high compressive strength and low absorption.[28] Table 5 shows the most used curing techniques. Wetting always occurs with the use of sprinklers or watering cans.

**Table 5** Methodologies for curing the soil-cement brick adopted

| Curing Process Adopted | References |
|---|---|
| Daily watering every day | Campos[59] |
| Successive wetting to keep brick damp for 7 days | ABCP[28] |
| After 12 h of conformation, soak for three times a day for 8 days. | CEPED[17] |
| Cure by immersion in water for 7 days and in air | Savastano & Agopyan[55] |
| Curing in a chamber with controlled temperature and humidity | Baldovino[56] |
| Laboratory cure air and water | Abdel[57] |
| Wet chamber for curing during the period of 7days | Ferreira[58] |

Although the type of cure used influenced the compressive strength, the benefit of using a wet cure was not evident. Most materials suffer from poor performance when tested in high humidity conditions.[57] Furthermore, if the curing conditions are inadequate, transverse shrinkage cracks form in the cemented layer.[58] In CEPED[17] shows that the ideal cure should be at least seven days protected from open air and humidified at least twice a day. The correct and ideal procedure would be to promote drying in continuous flow ovens and the steam removed from the chamber, a product of the evaporated water, could be used to cure the bricks, thus the curing time could be accelerated.

## Brick characterization tests

### Compressive strength

To perform the compressive strength test, the hydraulic press and Eq. 1 are used, where $R$ is the resistance in MPa, P is the load in $N$ and $A$ is the cross-sectional area in $mm^2$.

$$R = \frac{P}{A} \qquad (1)$$

The bricks must be broken after 7 and 28 days of curing. Compressive strength results should be greater than 2 MPa.[59] According to ASTM C67 specifications,[60] acceptable bricks must have a minimum 28-day compressive strength value of 10.3 MPa. Morel et al.[61] summarized that the mechanical behavior of bricks produced in a manual press generally present compressive strengths in a range of 1.5 to 3.0 MPa and higher values can be achieved using a hydraulic press and/or incorporating higher content of cement in the formulation. Table 6 show the results of several researchers who produced soil-cement bricks. It is concluded that the minimum strength after 7 days of curing must be 2 MPa and the maximum must reach 6 MPa.

**Table 6** Characteristics of soil-cement bricks

| BD (kg.cm-3) | AA (%) | CS (MPa) | Reference |
|---|---|---|---|
| 1,98 | 12,7 | 2,90 | Jitha[15] |
| - | 16 a 19 | 2,0 a 4,0 | Segantini[5] |
| 1,97 a 1,99 | 7,5 a 8,5 | 4 a 6 | Amaral[31] |
| 1,92 a 1,97 | 19,5 a 22,0 | 4,5 a 6,5 | Rodrigues[27] |
| - | 14 a 18 | 1,3 a 4,2 | Leonel[67] |
| - | 13 a 17 | 3,2 a 4,3 | França[72] |
| 1,69 a 1,79 | 16 a 19 | 1,5 a 2,5 | Sekhar[68] |
| 1,78 a 1,90 | 7 a 17 | 3 a 4 | Siqueira[66] |
| - | 9,70 a 10,35 | 0,30 a 1,55 | Cristina[70] |
| - | 17,0 a 19,3 | 1,2 a 1,8 | Jordan[71] |
| 1,59 a 1,75 | 15,5 a 17,0 | 2,42 a 3,38 | Vilela[10] |
| 1,64 a 1,76 | 10 a 12 | 3 a 5 | Lima[69] |
| - | - | 2,5 a 7,0 | Barros[73] |

BD, bulk density; AA, water absorption; CS, compressive strength

### Water absorption

Water absorption is a property that, according to NBR 8492,[62] must have a limit of 20% after 28 days of cure. Water absorption is the most important property of the brick, as it will define the possible degree of percolating water in the brick, in addition to favoring or not the reduction of its durability.[20,63] Water absorption is often used as an indicator of open porosity.[63,64] The absorption of bricks is significantly affected by raw materials and manufacturing methods. Generally, the lower the water absorption of the bricks, the greater their resistance to water damage.

For the water absorption test, the bricks must be weighed and immersed in water for 24 h. The water absorption (WA) can be determined by means of Eq. 2, where $m_2$ is the weight after immersion in water for 24 h, $m_1$ is the dry brick weight and $A$ is the absorption in %.

$$WA\% = (m_2 - m_1/m_1) \times 100 \qquad (2)$$

In Table 5 and Figure 4, the results of water absorption are presented. By calculating both the mean and the 95% confidence interval, it can be stated that the mean absorption used by manufacturers and researchers has ranged from 10% to 20%. Still, studies related to durability must be implemented with bricks with water absorption close to 20%, as it favors water percolation, which strongly compromises durability.

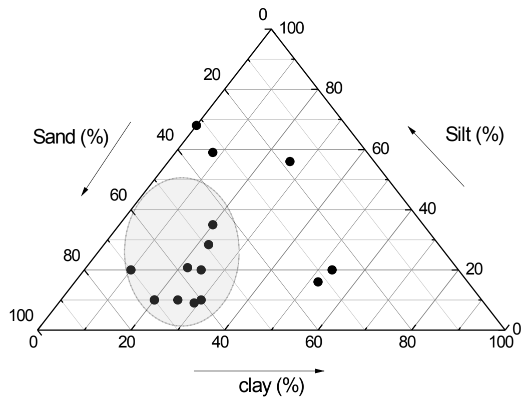


**Figure 4** Water absorption x compression strength of soil-cement bricks.

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**Bulk density**

Recommended brick density values range from 1540 kg/m³ to 1950 kg/m³.[64] According to Khoudija,[65] density is proportional to mechanical strength. The greater the mechanical strength, the greater the density. Table 6 show the density results of some researchers.

**Durability**

The durability test is determined following ABNT NBR 13554/2012.[74] According to the standard, bricks must be measured, weighed, and immersed in water, and then dried in an oven. After drying, it is measured again and subjected to brushing and weighing to assess how many particles can be removed. The operation is repeated six times. After the sixth cycle of the durability test by wetting and drying, the expansion must be equal to or less than 1% and the mass loss must not exceed the limits. It is important to evaluate this test not only in the presence of water but also for chemical reagents, as it is known that bricks are exposed to water for years and this can contain salts that change their pH and can influence its deterioration. The maximum limit assigned by the Brazilian Standard NBR 13554 is 10%.

In studies carried out by França[72] on cementitious soil blocks in which marble residues were incorporated in the formulation, a significant increase in strength was observed, as well as a surprising improvement in relation to the corresponding non-degraded blocks. This is due to the low porosity resulting from the wetting and drying cycles of the durability tests where the hydration of the cement particle is more effective.

In Quedraogo's work,[23] durability was determined in an air-conditioned chamber. Samples cut to dimensions of 15x15x5 cm³ after curing were sealed on all sides, leaving only one free. The bodies are then stored and initially in equilibrium with air at (23 ± 5) °C and (50 ± 5) % relative humidity. The criterion for equilibrium was a period long enough for the sample weight to stabilize so that two successive daily determinations (24 h apart) of the awake weight were within 0.1% of the test sample mass. The specimens were placed in a climatic chamber, defined to expose the samples to a daily cycle of relative humidity (8 h at 75% relative humidity and 16 h at 33% relative humidity), and their weight gains and losses were measured with an accuracy of 0.001 g.

In the Seco[75] work he incorporated lime residues into clay and subjected it to compaction and curing. In durability tests using European standards, it concluded that durability is not representative and needs further improvement.

Additionally, the most important work found in the literature was that of Ola[16] who subjected bricks with cement contents of 5 to 7% under water pressure and measured mass loss. In his work, he concludes that 7% cement is an acceptable percentage to guarantee the durability of the soil cement brick.

## Conclusion

The soil to produce soil-cement bricks must contain 10% to 30% of clay, 30% to 60% of sand + silt, and 6% to 10% of cement. Some manufacturers are migrating to other raw materials, such as phyllite, which have clay, feldspar, and quartz in their composition.

The composition of the soil must not contain the montmorillonite mineral clay, as it expands in contact with water, in addition to promoting considerable retraction, which may cause cracks in the brick. Furthermore, it is not recommended that the soil has organic matter, which can deteriorate the cement over time.

The grinding process is still primitive, as a finer grinding will certainly speed up reactions and may improve properties.

The presses used are normally manual, which limits the conformation pressure. Hydraulic presses, in which the pressure can be regulated, will ensure greater compaction density and, in turn, greater strength after curing. However, they demand greater production.

The process of humidification for cure is also still worthy of study, as it has been proven that humidification is necessary for at least seven days. Nonetheless, humidification via sprinklers is ineffective, as it humidifies a part of the brick, while others do not receive water.

Few studies have been carried out regarding the durability of the brick. Studies in which the water may be contaminated with chemicals or salts that may be present in its composition were not observed.

The soil-cement brick has gained space in civil construction in recent years. However, the lack of concrete methodologies for producing it is still evidence. Still, the product is an alternative to meet, above all, low-cost sustainable production.

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## Conflicts of interests

Author declares there are no conflicts of interests.

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