Chapter 2
Soil-Cement Bricks

Abstract This chapter describes the historical aspects, properties, and potential of soil-cement bricks.

Keywords Soil-cement bricks · Cement

2.1 Portland Cement

2.1.1 History

Portland cement is a fine powder presenting agglomerating, agglutinating, or binding properties that when under water, hardens and no longer decomposes when exposed to water again. Portland cement is composed of clinker and additions, and the former is its main component, which is present in all cements. Additions vary from one type of cement to another (ABCP 2002). The word CEMENT originates from the Latin word CAEMENTU, which in the old Rome designated a kind of natural stone that did not square. Cement dates back about 4500 years. The imposing monuments of ancient Egypt already used an alloy composed of a mixture of calcined gypsum. The great Greek and Roman works such as the Pantheon and the Colosseum were built using volcanic soils from the Greek island of Santorino or the surroundings of Italian town Pozzuoli, which had hardening properties under the action of water (ABCP 2000).The major step in the development of cement was taken in 1756 by Englishman John Smeaton, who managed to obtain a high-strength product through calcination of soft and clayey limestone. In 1818, Frenchman Vicat obtained results similar to those of Smeaton by mixing clayey and limestone components. He is considered the inventor of artificial cement. In 1824, English builder Joseph Aspdin burned together limestone and clay, turning them into a fine powder. He realized that he had obtained a mixture which, after drying, became as hard as the stones used in construction. In Brazil, the first attempt to apply knowledge related to the manufacture of Portland cement apparently occurred in 1888, when Commander Antônio Proost Rodovalho built up a factory in Santo

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Antônio farm of his property located in Sorocaba, SP, Brazil. Subsequently, several sporadic initiatives to manufacture Portland cement were developed. A small production facility was operated for three months in 1892 in the island of Tiriri, Paraiba. The Rodovalho plant operated in 1897–1904, returning to work in 1907 and definitively extinguished in 1918. In Cachoeiro do Itapemirim, the government of the state of Espírito Santo founded a factory in 1912 that operated until 1924, resuming operation in 1936, after modernization. All these initiatives were only mere attempts that culminated in 1924 with the establishment by the Brazilian Company of Portland Cement in Perus, state of São Paulo, whose construction can be considered a hallmark of the Brazilian cement industry. The first tons were produced and placed on the market in 1926. Until then, cement consumption in the country depended exclusively on imported products. Domestic production gradually increased with the implementation of new plants and the share of imported products fluctuated during the following decades until almost disappearing in current days.

2.1.2 Manufacture

The raw material is extracted from mines by usual processes for the exploitation of mineral deposits. Limestone may have high hardness, requiring the use of explosives followed by crushing, or low hardness requiring only the use of disintegrators to be reduced to the size of maximum particle diameter of 1 cm. Clays containing silicates, alumina, and iron oxide are usually capable of being directly mixed with limestone. Limestone and clays, in predetermined proportions, are sent to the grinding mill (ball, bar, and roller mill), where the intimate mixing of raw materials occurs and at the same time, they are turned into powder to reduce their particle size diameter to 0.050 mm, on average. The determination of the percentage of each raw material in the raw mixture essentially depends on the chemical composition of raw materials and the desired composition to be obtained for Portland cement when the manufacturing process is completed. During the manufacturing process, the raw material and the crude mixture are chemically analyzed numerous times at intervals of 1 h and sometimes every half hour, and according to the test results, the laboratory indicates the percentages of each raw material that should compose the crude mixture. The properly dosed raw material and reduced to a very fine powder after grinding should have its homogeneity ensuring the best possible way. Once pulverized and properly mixed in suitable dose, the raw material undergoes heat treatment which can be seen in Table 2.1.

In the furnace, as a result of treatment, the raw material is transformed into clinker. At the outlet, the material is presented in the form of balls of maximum diameter ranging from 1 to 3 cm. The balls that form the clinker leave the furnace at temperature of about 1200 to 1300 °C, as there is a temperature lowering in the final stage, still within the furnace. The clinker leaves the furnace and enters the cooling equipment, which can be of various types. Its purpose is to reduce temperature,

Table 2.1 Heat treatment of the raw material after dosing

Temperature	Process
Up to 100 °C	Evaporation of free water
500 °C and above	Dehydroxylation of clay minerals
900 °C and above	Crystallization of decomposed clay-mineral compounds
900 °C and above	Decomposition of carbonate
900–1200 °C	Reaction of CaO with sand-aluminate compounds
1250–1280 °C	Beginning of the formation of glassy phase
Above 1280 °C	Formação de vidro e dos compostos do cimento (clinkerization)

more or less quickly, by the passage of a cold draft inside the clinker. Depending on the facility, the clinker presents temperature between 50 and 70 °C, on average, at the output of the cooler. Portland clinker thus obtained is conducted to the final grinding, receiving before a certain amount of gypsum, limited by the standard which aims to control in setting the start time.

2.2 Soil-Cement Bricks

2.2.1 History

The first known soil-cement application for residential building is dated to about 10,000 years in the construction of the city of Jericho, which was built entirely with soil (but the stabilizer used was animal urine and vegetable waste) (Abiko 1995). When common Portland cement is added to soil, the resulting building material is termed soil-cement and according to Neves (2000), soil-cement is a mixture of soil, cement, and water that when compressed acquires mechanical strength and durability necessary for construction purposes. Soil-cement is a very old building material and finds its roots in the changes of an even older material, soil-ash. The addition of cement to the soil results in a material that does not undergo large volume variation by the absorption and loss of humidity, does not completely deteriorate when submerged in water, and presents high compression strength and durability due to its lower permeability (Grande 2003). Soil-cement is obtained by mixing soil, pulverized and moistened at optimum moisture content, to 7–14 % Portland cement in relation to the volume of compacted soil (Vargas 1977). It is believed that British engineer H.E. Brook-Bradley, at the late nineteenth century, was the pioneer in using this mixture, initially for the treatment of road beds and tracks for horse-driven vehicles in Southern England. In Brazil, soil-cement was used in the production of road bases and studies were focused on this end. In 1948, however, the Brazilian Portland Cement Association—ABCP, suggesting another use for this material, published in its bulletin No. 54—houses were made with soil-cement walls—in which, motivated by the success achieved in some

experiments, proposes to use this material for the construction of monolithic walls (Neves 1978). However, the first official record of its use in Brazil is in the building, completed in 1948, of the headquarters of the English Farm, in the city of Petrópolis —RJ (Conciani and Oliveira 2005). Soil-cement is a low-cost alternative material obtained by the mixture of soil, cement, and a little water in suitable proportions. At first, this mixture seems a wet mixture and, after compression and setting, it hardens and gains enough consistency and durability over time for many applications in rural and urban areas. Soil-cement is an evolution of past construction materials, like clay and mud. Natural adhesives of varying characteristics have been replaced by an industrial product of controlled quality: the cement. The use of soil-cement in Brazil has, since 1948, helped meeting these needs, being today already widespread. It has been demonstrated that the application of soil-stabilizing technique brings the following advantages:

- Soil-cement has been consecrated as an alternative technology for offering the main component of the mixture—soil—in abundance in nature and generally available on the construction site or close to it;
- The constructive process of the soil-cement mixture is very simple and can be conducted by unskilled labor;
- It offers good comfort conditions, comparable to brick and masonry buildings or ceramic blocks, offering no conditions for the proliferation of insects harmful to public health, meeting minimum living conditions;
- This material has good resistance and perfect waterproofing features, resisting weathering and humidity, facilitating conservation;
- The application of roughcast or plaster mortar is unnecessary due to the smooth finish of monolithic walls as a result of the perfection of pressed faces (walls) and material impermeability requiring only the application of a simple cement-based painting, further increasing its impermeability, as well as visual appearance, comfort, and hygiene;
- Low aggression to the environment, since it eliminates the firing process;
- Low transport costs when produced at the construction site;
- Low cost compared to conventional masonry.

Soil-cement has been used for decades, but its use is still very limited. As a result, entire forests are devastated to produce ceramic bricks that, after all, are more expensive. Despite these positive points, in Brazil, the interest by the soil-stabilizing method is more significant in paving works (about 90 % of the bases of our roads are made of compacted soil-cement), dams and retaining walls, with secondary application in civil construction due to the lack of technical knowledge of professionals involved in the various segments of society. Given this reality, studies aimed at developing and disseminating this technique that is needed.

2.2.2 Soil-Cement Strength

In the 80s, interested in spreading the soil-cement technology, company SUPERTOR manufacturer of machines and for soil-cement technology published a handbook on the operation and use of such technology. This handbook presents some factors that influence the strength properties of soil-cement brick such as:

(a) Soil characteristics;
(b) Cement content in the mixture;
(c) Degree of fineness of the cement used;
(d) Degree of homogenization of the mixture;
(e) Densification of the mixture in the pressing stage (or packing factor of the mixture);
(f) Setting time and mixture condition after pressing;
(g) Additives used.

The cement content used to stabilize the soil improves and increases the material strength and durability. The proper combination of these factors optimizes strength. It is well known that soils with higher proportion of sand in their composition, in most cases, will lead to greater soil-cement strength. The influence of other factors such as the limits of consistency, particle size distribution, and types of clay minerals should also be considered. Good homogenization of the mixture is critical. Cement should be added to dry soil and mixed until uniform color is achieved (CEBRACE 1981). Only after homogenization, water is added in adequate amounts. Resistance increases proportionally to the cement content used; however, it should be limited to an ideal content that provides the brick or blocks the required strength without unnecessary increase in the cost of the final product (ABCP 1985). Tests carried out in soil-cement specimens showed strength gains as a function of the setting time. This behavior is associated with interactions of clay mineral components and cement that, according to several authors, are little-known reactions. There seems to be some consensus that the hardening and strength gain of the mixture over time are largely associated to the reactions among clay mineral components and the lime released in the cement hydration (Segantini and Carvalho 1994). According to Ceratti and Casanova (1988), to study the strength gain of soil stabilized with cement, one must carefully study the following aspects:

- Genesis, composition and soil properties;
- Physical and chemical characteristics of soils;
- Knowledge of the cement used as binder.

Figure 2.1 shows some soil-cement bricks manufactured with different soil compositions.

Fig. 2.1 Examples of soil-cement bricks

2.2.3 *Criteria for the Selection of the Soil to Be Used in the Manufacture of Soil-Cement Bricks*

The Brazilian Association of Technical Standards (ABNT 1989) through its NBR 10832 and 10833 standards establishes criteria for the selection of soils for use in the manufacture of solid soil-cement bricks (Table 2.2).

It is recommended the use of soils with 70 % sand and 30 % clay and 4–5 % moisture content. Sandy soils require lower amount of cement for stabilization when compared to clayey soils. CEPED suggests an assay to determine the soil suitability and its possible use for the manufacture of soil-cement bricks. It is suggested to place an amount of soil in a box of dimensions 60 × 8.5 × 3.5 cm and allow it rest for 7 days. After this period, if the contraction observed in the soil is

Table 2.2 Criteria established by Brazilian standards for the manufacture of soil-cement bricks

Features	Requirement (%)
% soil passing in ABNT 4.8 mm sieve (number 4)	100
% soil passing in ABNT 0.075 mm sieve (number 200)	10–50
Liquid limit	<45
Plasticity limit	<18

Table 2.3 Values established by the Brazilian standard for soil-cement bricks

Limit values	
Compressive strength (MPa)	≥2
Water absorption (%)	≤20

less than 2 cm in the length direction of the box and there are no cracks, the soil can be considered suitable for use in soil-cement mixtures (Neves 1989). If the soil available does not meet the proposed criteria, it can be mixed with other soils in order to obtain the necessary features. Usually, the use of soils with organic matter content less than 2 % is recommend. Regarding the cement content, the Brazilian Portland Cement Association (ABCP 2000) recommends the addition of 7–14 % of cement content to the mass, depending on the soil type. Sandy soils are stabilized with lower cement content when compared to clayey soils. Neves (1978) shows the need for wetting the bricks produced, stressing that the absence of such procedure can lead to loss of strength of about 40 %. This procedure aims to prevent water evaporation or exchange of moisture with the environment for a minimum period of 7 days. The Brazilian Association of Technical Standards (ABNT) through its NBR 10836 standard sets limit values for compressive strength and water absorption for soil-cement bricks (Table 2.3).

2.3 Soil-Cement Bricks Incorporated with Waste Materials

Industrial activities generate enormous amounts of solid waste, which can cause adverse effects to the environment. In Brazil, most of this residue has been improperly disposed into the environment causing environmental impacts.

Many studies have been reported in literature about soil-cement bricks with the addition of different waste materials. Table 2.4 summarizes the results obtained for some waste materials investigated in literature.

Faganello (2006) investigated the characteristics of soil-cement specimens added with gravel tailings. The results showed that the compressive strength of samples increases with increased cement contents. Lima (2010) studied the durability of green soil-cement bricks incorporated with granite waste. The authors used granite waste from industries located in the industrial district of Campina Grande-PB, Brazil. They also observed that strength decreased with increasing amounts of granite residue. When incorporated into soil-cement bricks, increased water absorption, weight loss, and volume change of bricks were observed as the waste content increased. Simone (2013) observed that the incorporation of ornamental stone waste caused changes in the technological properties of soil-cement specimens. It has been found that the ornamental stone waste tends to decline to increase the compressive strength and decrease the water absorption of test specimens with the addition of 40 % waste. All specimens with additions of 0–40 % ornamental

Table 2.4 Comparative strength and water absorption values reported in literature for soil-cement bricks added of waste materials

Waste materials	Compressive strength (MPa)	Water absorption (%)
Brita (Faganello 2006)	1.5–3.2	–
Ornamental rock (Ribeiro 2013)	3.6–9.7	17–21
Marble and Granite (Miranda 2007)	2.12–3.29	19.52–20.46
Granite (Lima 2009, 2010)	–	16–24
Eggshell (Amaral and Smith 2013)	4–4.5	7.5– 21
Granite (Ribeiro 2014)	4–5.5	20–21
Grits (Siqueira 2013)	5–6	18– 22
Ceramic waste (Silva et al 2014)	0.8–3	16–18
Rice/Brachiaria husk (Ferreira 2008)	0.62–3	19.96–11.42

stone waste exceeded the minimum values for compressive strength set by NBR 10834 (ABNT 1994), with water absorption values below 22 %, as recommended by Brazilian standards. Matheus, 2013 studied the incorporation of eggshell waste, generated in large amounts in the food industry, into soil-cement bricks. Eggshell waste is rich in calcium carbonate ($CaCO_3$) and is considered to be a solid waste material of very complex and difficult final disposal. The results indicate that eggshell waste can be used in soil-cement bricks with excellent technical properties, in the range up to 30 wt%, as a partial replacement for Portland cement. Silva 2014 studied the incorporation of ceramic waste (construction and demolition materials) into soil-cement bricks. This type of waste presents a wide variation in chemical composition, depending on the collection of the material in the construction works, which leads to a wide variation in the properties of produced bricks. Briefly, it could be inferred that soil-cement bricks provide good conditions for the incorporation of different types of industrial waste. The addition of such wastes produces soil-cement bricks with properties within the Brazilian standards providing good opportunity for the use of these materials and consequently greater relief for landfills where these materials are usually dumped and therefore environmental improvements.

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