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Stabilization effects on the thermal conductivity and sorption behavior of earth bricks

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HIGHLIGHTS

- Effect of chemical stabilization on the hygrothermal properties of CEB is discussed.
- Thermal conductivity of earth bricks increases with increasing stabilizer content.
- Addition of stabilizers to the soil reduces the material vapor permeability.
- Suitability of four moisture sorption models are evaluated for earth bricks.

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ABSTRACT

The renaissance of earth building is mainly motivated by the thermal and hygric properties of the material. These earthen materials qualities lead to improve the hygrothermal conditions in indoor environment. Today, stabilization of earth bricks by addition of chemical stabilizers is a common approach used to maintain and improve its use for construction. Although the addition of cementitious stabilizing agents enhances the engineering properties of soil, it is not the case for their hygrothermal properties. In this work, an experimental investigation is performed on stabilizers effects on thermal conductivity and moisture sorption isotherms of compressed earth bricks. Four water vapor sorption models are evaluated by fitting the sorption isotherms data of un-stabilized and stabilized compressed earth bricks. Soil blocks have been manufacturing with locally material. They are stabilized with cement or lime contents of 5%, 8%, 10% and 12%.

The results show that the thermal conductivity increases as a function of stabilizers contents. The measured sorption data of earth bricks showed that stabilization induces a reduction of material water vapor permeability. It's found that Henderson model is the best for fitting sorption isotherms data over the studied range of relative humidity.

1. Introduction

Reducing energy consumption in building sector has been considered as the most promising way to mitigate climate change. The use of sustainable and healthy environmental materials for the building industry appears as a good solution to reduce energy demand while maintaining high indoor quality.

Earth is one of the oldest construction materials that was used since the birth of humanity. Moreover, 15% of the architectural works inscribed on UNESCO world heritage list was built in earth [1]. It presents several environmental, social and economic benefits that allow it to be an important alternative material for the building industry. The performance of this ecological material is mainly depending on its hygrothermal behavior. This is related to the thermal and hygric properties of the materials and can be characterized by thermal conductivity, heat capacity, sorption isotherms and water vapor permeability.

The growing interest in this traditional earth construction technique has led to numerous research studies that have outlined its benefits. In comparison with industrial materials, many studies [2,3] have demonstrated that the use of earth-based materials participates in reduction of environmental impacts as well as in energetic economy. Other studies [4–7] have shown that earth bricks as a building materials have high potential to create a healthy

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environment and to regulate the hygrothermal conditions inside a building for its occupants. Thus, earthen walls have thermal and moisture buffering capacity that stabilize the relative humidity inside the building and consequently increase indoor comfort. Compared to other traditional materials, the clay base materials show the best humidity buffering potential and have the highest potential to regulate the indoor humidity [8,9]. Interested on the thermal performance of unfired clay, El Fgaier et al. [10] found that the earth wall reduces the fluctuation of the outside temperature.

However, earth materials are suffering from high sensitivity to environment changes [4,11]. The significant capacity to absorb atmospheric moisture contributes to its rapid deterioration [12,13]. This disadvantage has generate interest in research for innovative solutions in order to improve the characteristics of earthen materials.

In recent years, stabilization, which refers to the process of mixing additives with soil to improve its volume stability, strength, permeability and durability [14], became a common approach to prevent water attacks and enhance resistance to climate change. Soil can be stabilized by manual compaction, mechanical compaction or by the addition of cementitious material or by incorporation of reinforcing elements [15–26]. These processes induce a considerable development of many earth construction techniques such as compressed earth bricks (CEB) and stabilized earth bricks (SEB). These innovative techniques make earthen materials compatible with required application in building.

While the effects of stabilization on mechanical behavior of earthen materials are well studied and well known [12,13,15–17], a very few studies focused on the impact that stabilization may have on the thermal and hygric properties of earth bricks. Among such studies, Hall and Allinson [18] carried out experimental study to characterize the hygrothermal functional properties of stabilized rammed earth materials (SRE). Luizzi et al. [19] investigated the hygrothermal behavior and relative humidity buffering of unfired and hydrated lime stabilized clay composites in a Mediterranean climate. They found that the addition of stabilizer increases the moisture buffering capacity. Effects of stabilizers on water absorption of compressed earth blocks have been studied by Fopossi et al. [20]. McGregor et al. [21] also worked on the influence of stabilization method on the buffering capacity of compressed earth blocks. More recently (2017), Arrigoni et al. [22] focused on the reduction of hygroscopic performance of rammed earth under stabilization. These studies showed the opposite results compared with the study of Luizzi et al. [19]. The findings revealed that the chemical treatment has often decreases the hygroscopicity for the soil studied and increases its water vapor resistance. Some other studies have dealt with the thermal behavior of stabilized earth bricks [15,23–25]. Meukam et al. [15] studied the thermophysical characteristics of cement stabilized compressed clay. Adam and Jones [23] worked on the thermal conductivity of lime/cement stabilized hollow and plain earth blocks. Ashour et al. [24] also characterized the thermal conductivity of unfired earth bricks reinforced by agricultural wastes with cement and gypsum. Balagi et al. [25] investigated the influence of varying mix proportions on thermal performance of soil-cement blocks. They showed that thermal conductivity increases in response to increasing cement content of the blocks. Lastly, Zhang et al. [26] found that, for a given bulk density, changes in cement content result in a small variation in thermal conductivity of cement stabilized earth blocks.

The objective of this paper is to improve the understanding of hygrothermal behavior of compressed earth bricks (CEB) as a bio-based material used in building in Tunisia. So, we investigate how the hygrothermal properties of CEB are influenced by the addition of chemical stabilizers. Firstly, we present the characterization of the local soil used in the production of these building materials. Then, we report experimental investigations to determine the effect of chemical stabilization by cement and lime on the thermal conductivity and the sorption isotherms of un-stabilized earth bricks (USEB) and stabilized earth bricks (SEB). Finally, a mathematical investigation is performed in order to find suitable moisture sorption isotherm equation to describe the experimental data.

2. Material and methods

2.1. Tested material

In this investigation, the soil used for the preparation of the samples was taken from the region of Sidi Amor in Ariana (Tunisia). Fig. 1 gives the particle size distribution curve as compared to the lower and upper limits for compressed earth blocks [27]. In accordance with Houben et al. [27], the range of particle distribution suitable for building of compressed earth block is: 0–40% gravel, 25–80% sand, 10–25% silts and 8–30% clays. The granular composition of the soil (>80 μm) has been determined using wet sieving analysis method. The result indicates that the soil has 42.12% sand, 57.08% clay and silt and 0.8% gravel. This means that the studied soil meet the minimum requirements for the manufacture of compressed earth bricks. However, no grading correction is applied. This soil has a liquid limit of 22.5% and a plasticity index of 6.27% and hence could be classified as moderately plastic silt type A4 according to the American Association of State Highway Transportation Officials (AASHTO) system. Its bulk and true density are 1090 kg/m^3 and 2470 kg/m^3 respectively. Results of this work are summarized in Table 1.

Stabilization is achieved by using Ordinary Portland Cement (CEM II A-L 32.5 N) and high-calcium hydrated lime (CL 90-S). The ratios of stabilizer are added in different percentages ranging from 5% to 12% per dry weight of sample.

2.2. Sample preparation

At first, the oversized granules of soil are removed and only the particles that passing through 8 mm sieve are used for making the bricks. It was then put in an oven dried to constant mass at 105 °C. The required quantities of soil, cement and hydrated lime were initially mixed in a dry condition until a uniform mixture is obtained. Afterwards, the mixture soil-stabilizers was mixed with water to approximately its plastic limit. The amount of water is about 13–17%; it depends on the type and the ratio of stabilizer. Wet mixture was then put in the mould and compacted to a known

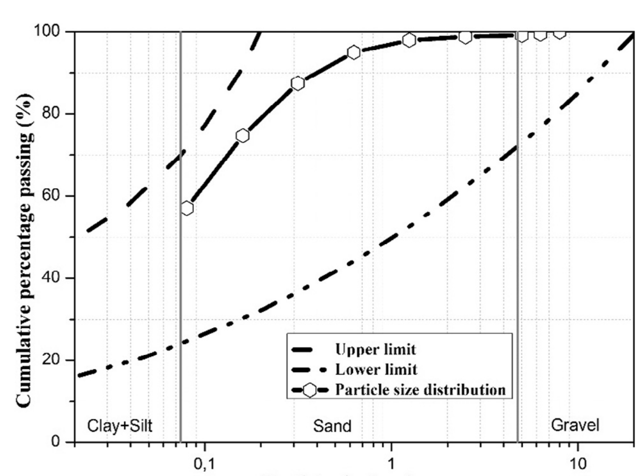

Fig. 1. Particle size distribution of the experimental soil.