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Hygrothermal properties of compressed earthen bricks

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HIGHLIGHTS

- Thermal conductivity of compressed earthen bricks increases with increasing bulk density.
- The response of compressed earthen bricks to a relative humidity change is rather fast.
- Hysteresis values of compressed earthen bricks increased with increasing relative humidity.
- Hygroscopic properties of compressed earthen bricks with different bulk densities are close to each other.

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ABSTRACT

The present study investigates the relationship between bulk density and hygrothermal behaviour of compressed earthen bricks. The experimental results show that the thermal conductivity linearly increases from 0.5228 W/(m K) to 0.9308 W/(m K) as the bulk density increases, and that the equilibrium moisture content increases with increasing relative humidity. Hysteresis effects are observed. When relative humidity changes, compressed earthen bricks usually reach an equilibrium in four days and it means compressed earthen bricks can be used to regulate indoor relative humidity. The hysteresis values of compressed earthen bricks with different bulk densities are close to each other, especially low relative humidity, as the results of Brunauer-Emmett-Teller (BET) show that samples with different bulk densities have similar porous structure including specific surface area (15.5008–16.2091 m^2/g), micropore volume (0.000867–0.001221 cm^3/g) and mesopore volume (0.030785–0.032239 cm^3/g). Moreover, the hysteresis loops in this study belong to the type H3 hysteresis loops which indicate that there are some slitlike pores inside the matrix.

1. Introduction

The increased use of non-renewable resources and increased greenhouse gas emissions result in growing environmental problems. The impact of building performance on the ecological environment gradually attracts more and more public attention. In the western world, buildings account for approximately a third of both all energy use and greenhouse gas emissions [1]. In China, energy consumption in commercial and residential buildings has considerably increased in recent years, the building energy demand will account for 35% of the total energy consumption in 2020 [2]. The energy requirement for heating, cooling and ventilation accounts for the major part of the building energy consumption. Therefore, several solutions have been implemented to reduce energy consumption, e.g. promotion of increased levels of thermal insulation, use of renewable energy and promotion of energy efficiency [3,4]. Besides, the application of the environmental friendly building materials will be important to reduce embodied emissions (i.e. emission related to building material production and maintenance) [4]. Earth-based materials may be important in this respect [5,6]. They can also have hygrothermal properties that can result in a more stable indoor environment [7].

The hygrothermal properties of building materials can influence the ability of indoor climate stabilization of buildings. For example, a well-insulated building envelope can reduce the heat transfer through the building envelope and weaken the impact of outdoor

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climate changes on indoor environment. Materials with good moisture storage abilities, on the other hand, are able to absorb water vapour from the air when the relative humidity increases and release water vapour when the relative humidity decreases in order to maintaining a more stable indoor relative humidity [7,8]. In situations where a more stable indoor relative humidity is desirable, the building envelope should have the ability of moisture storage.

Soil and/or earthen materials have been used for construction purpose for thousands years; and nowadays, approximately one half of the world's population still live in earthen buildings [7,9]. Compared with some common building envelope materials, i.e. fired clay bricks and concrete, earthen materials have a larger moisture capacity [10]. This can be explained from that earthen materials are typical porous materials that have a moisture storage capability caused by single layer adsorption, multi-layer adsorption and capillary condensation [11]. More importantly, as a natural, sustainable and eco-friendly building material, the abundant source of earthen materials can lead to direct site-to-service application, thus reducing the costs caused by acquisition, transportation and production.

During the last few years, a growing interest has appeared for the hygrothermal properties of earthen materials. Liuzzi et al. [9] and Cagnon et al. [12], respectively, conducted experimental studies to compare the thermal conductivity values between earthen bricks from different regions; the results showed that the differences of mineral composition and grading level have a huge impact on the thermal conductivity values of earthen bricks. Hall et al. [13], Mansour et al. [14] and Tang et al. [15] studied the effect of bulk density, water content and degree of saturation on the thermal conductivity of compressed earthen bricks. Results demonstrated that there is a linear correlation between the thermal conductivity and density and then the thermal conductivity significantly increases with increasing degree of saturation. Taallah et al. [16], Ashour et al. [17] and Adam et al. [18] respectively added natural fibers and chemical additives into earthen materials to produce stabilized earthen materials, where the results demonstrated that natural fibers are able to reduce the thermal conductivity as the fibers contain a lot of pores. Conversely, cementitious products formed by hydration reaction increase the thermal conductivity of stabilized earthen materials. For hygroscopic behaviour of earthen bricks, Liuzzi et al. [9] and Cagnon et al. [12] measured earthen bricks from different regions and results indicated that there are obvious differences between them as mineral composition of earthen materials has a serious influence on the adsorption and desorption ability. Ashour et al. [19,20] presented that addition of natural fibers increases the equilibrium moisture content of earthen materials; however, cementitious materials, i.e. cement, lime and gypsum, have the opposite effect on the equilibrium moisture content [11,20]. McGregor et al. [21] indicated that the variation of density influences the pore structure and therefore affects the capillary condensation which leads to the significant increase of the equilibrium moisture content. Raimondo et al. [22] and Randazzo et al. [23] measured the pore size and specific surface area of earthen materials by helium pycnometry and Brunauer-Emmett-Teller (BET) method and obtained the correlation between the porous structure and hygroscopic behaviour.

It is noteworthy that the presented studies have essentially considered the thermal properties or hygroscopic properties of earthen materials, and very few papers have investigated the hygrothermal properties of earthen materials and, in particular, compressed earthen bricks. The objective of this study is to investigate how the porous structures of compressed earthen bricks vary with change of bulk density and then the effect of the porous structure on the hygrothermal properties of compressed earthen bricks. Additionally, such studies presented that bulk density has a significant effect on thermal or hygroscopic properties of earthen materials and that bulk density is a rural macroscopic physical indicator which is easier to control in the production process of earthen bricks. Furthermore, the aim of this study is to try to obtain a relationship between hygrothermal properties and bulk density in order to guide the preparation of compressed earthen bricks to reach the requirements concerning hygrothermal behaviour.

2. Experimental

2.1. Materials

The earthen materials used in this investigation derive from Turpan, located at 42°26′ N, 89°5′ W in the Xinjiang Uygur Autonomous Region, Northwest of China. The grading curves and the particle sizes of the earthen materials were investigated by grain size analysis, according to GB/T 50123-1999 [24]. The composition of the earthen material is 17% clay (less than 5 μm), 51% silt (between 5 and 50 μm) and 32% sand (between 50 and 2000 μm). The test results are presented in Fig. 1.

2.2. Sample preparation

Before the preparation of compressed earthen samples, the earthen material was sieved to remove the oversized gravel (larger than 2 mm diameter) and organic matter. The sieved material was dried in air at a temperature of 105 °C to obtain a constant weight. To produce the compressed earthen samples at different bulk densities, the dried material put into the mould was controlled and the mass of dried material inside the mould was determined by the calculation of target bulk density times volume of mould. The classification of bulk density includes 1.5, 1.7, 1.9 and 2.1 g/cm^3 and the sample dimensions were 50 mm × 50 mm × 25 mm. Samples were prepared by a hydraulic press under a pressure of from 20 to 70 kN, as shown in Fig. 2. After compaction, the samples were placed in controlled laboratory conditions for 14 days to avoid cracking. The environmental temperature and relative humidity in the laboratory during the drying process were 20 °C and 60%, respectively.

2.3. Characterization

2.3.1. Physical and chemical characterization

The earthen material was characterized by some basic tests including Atterberg limit and chemical composition. The Atterberg

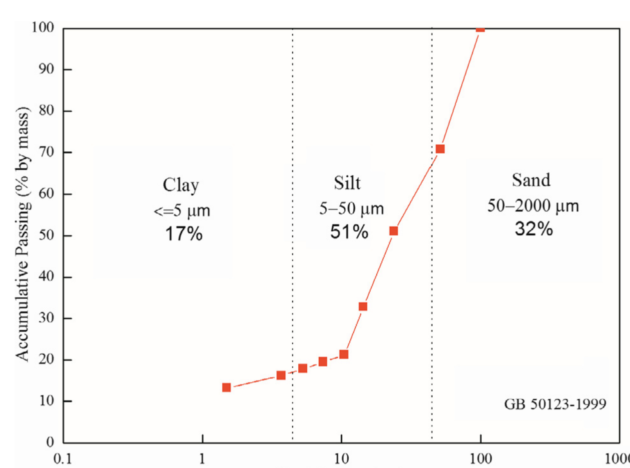

Fig. 1. Grain size distribution of earthen material used.