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Equilibrium moisture content of clay bricks: The influence of the porous structure

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Abstract

The comprehension of the influence exerted by the material microstructure on the hygrometric properties of clay bricks plays a fundamental role in order to control the condensation phenomena and to avoid the deterioration of the masonry structure. The equilibrium moisture content (MEq) of ordinary and lightweight clay bricks was measured and the correlation with microstructure and pore morphology was investigated. The influence of the pore size and specific surface on the amount of MEq was found to be prevalent when compared to the other physical variables. A statistical model was also set up in order to predict the MEq values.

Keywords: Clay bricks; Water vapour absorption; Equilibrium moisture content; Microstructure; Pore size

1. Introduction

The deterioration of porous building materials is mainly due to the structure/water interactions, which, depending on the material characteristics, the physical state of water (liquid or vapour) and the environmental conditions, may be of different magnitude involving different sorption mechanisms [1]. In particular, the absorption of humidity from air, the capillary rise, the rain penetration and the condensation phenomena can lead to the formation of superficial moisture and, consequently, to the wearing and tearing of the structure [2,3].

The knowledge of the hygrometric properties of clay bricks and the influence exerted by the material microstructure plays a fundamental role in the assessment of these phenomena. Furthermore, the moisture content of clay bricks is of substantial significance for the insulation properties of the masonry, affecting considerably its thermal conductivity [4–8].

Notwithstanding the interest of this subject, few studies in the literature dealt with the water/masonry interactions; most of them concern the liquid capillary suction properties, with determination of the water absorption rate and the suction coefficient [9–14], while just few others focused on the water vapour permeability [15–17] or moisture content at equilibrium [4–8]. Generally, the available studies describe the water (liquid or vapour) transfer through porous materials and the storage of the residual humidity in their structure, using different physical and mathematical models which require the knowledge to some extent of the pore system, at least in terms of porosity and pore size distribution. However, a detailed microstructural characterization of clay bricks is often lacking, making it difficult any appraisal of the different approaches and models.

The measurement of the moisture content at equilibrium (MEq) of ordinary and lightweight bricks was already performed [4–6], pointing out some correlations between the MEq on one hand and the pore-specific surface (PSS), bulk density, total porosity and mean pore size on the other hand. The MEq was found to be positively related to the PSS, but no significant data about the relationships with other physical or textural parameters came out. Anyway, for most authors the bulk density is the only parameter considered to compare the thermo-hygrometric

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performances of different clay bricks, even if this variable proved to be unreliable to predict the MEq values [5,6].

This study is aimed at the experimental determination of the MEq on a series of ordinary and lightweight clay bricks, in order to draw a picture representative of their hygrometric properties. The problem was approached by the material point of view, in order to understand better the affinity of the brick structure towards the humidity absorption. In this standview, the influence of brick microstructure (particularly amount, shape and size of pores) on MEq was thoroughly investigated, through a statistical analysis of data by binary and multivariate techniques, trying to develop a simple predictional model of the MEq.

2. Materials and methods

Two different typologies of industrially manufactured clay bricks were collected, as both lightweight (A_L and S_L) and ordinary products (A and S). For each brick typology, 10 specimens were prepared by cutting $20 \times 10 \times 8$ mm bars out the industrial products, which were then dried at $105 \pm 0.5\,^{\circ}C$ until constant weight. The amount of absorbed water in function of time was monitored over several weeks in a climatic cell at six different relative humidity values (20%, 40%, 50%, 60%, 70% and 80%) under isothermal conditions (22 °C). Once the asynthotic limit was approached, the MEq was calculated as the amount of absorbed water per dry volume ($kg\,m^{-3}$) with an experimental error around 3% relative.

The bricks were characterized by the physical and microstructural points of view. Open porosity (OP) and bulk density (BD) were determined by water saturation and Archimede's principle, by measuring the dry weight, the water-saturated weight and the weight suspended in water, according to ASTM C 373. Total porosity (TP) was calculated as $TP = 1 - (BD/SW)$, where SW is the specific weight measured by water pycnometry, according to ASTM C 329. The experimental uncertainty is as low as 0.2% vol (OP and TP) and $0.002\,kg\,dm^{-3}$ (BD).

The pore size distribution (in the 0.005–100 μm range) was determined by mercury intrusion porosimetry (Carlo Erba Porosimeter 2000); the mean pore size (MPS), the percentage of pores in the 10–50 nm range (P50), the kurtosis of the distribution (Kurt) were drawn out with an experimental uncertainty of about 1% relative.

The PSS analysis was performed by nitrogen absorption (Micromeritics FlowSorb II 2300) following the BET single point method according to ASTM C 1069 (analytical error about 5% relative).

A statistical elaboration of data was performed by linear binary correlation and multivariate techniques (factor analysis, multiple linear regression analysis) using the StatSoft Statistica 5.0 software. Factor analysis was carried out on the main physical and microstructural variables extracting principal components (two factors according to the screen test for eigenvalues). Multiple linear regression was executed by the forward stepwise method, including intercept in the model and setting $F = 1.00$ to enter and $F = 0.00$ to remove.

3. Results and discussion

3.1. Moisture content at equilibrium

The determination of the MEq values at different relative humidities provided strictly correlated results: the higher the relative humidity, the larger the amount of water absorbed. In the correlation with the ceramic porous structure, only the MEq measured at a relative humidity of 70% has been reported, since it is easily related to the moisture content measured in the other different conditions by the equation shown in Fig. 1.

The MEq of samples A and A_L is, respectively, in the 4–6 and 10–12 $kg\,m^{-3}$ ranges, while the MEq values shown by sample S (12–15 $kg\,m^{-3}$) and S_L (5–11 $kg\,m^{-3}$) follow the opposite trend, being the lightweight brick less hygroscopic (Table 1). The comparison of these data with those found in the literature is difficult mainly for two reasons: the different size of the specimens (slabs [4,5] or ground brick [6]), and the different experimental conditions (relative humidity and temperature).

However, the equilibrium moisture content of granular materials from 20 different walling bricks (2–32 $kg\,m^{-3}$ at 86% of relative humidity) presented by Schmidt [6] accounts for very large differences in terms of hygroscopic behaviour. This great dispersion of data is attributed by the author to some factors directly affecting the increase in weight, such as the possible formation of $Ca(OH)_2$, caused by the moisture absorption of ceramic bodies containing CaO, or the underfiring of some samples, which brings about the presence of more reactive sheet silicates as well as a larger internal surface.

The equilibrium moisture content of ordinary and lightweight products, fired at two different temperatures (850 and 1050 °C), was also measured by Rimpel [7,8]; the

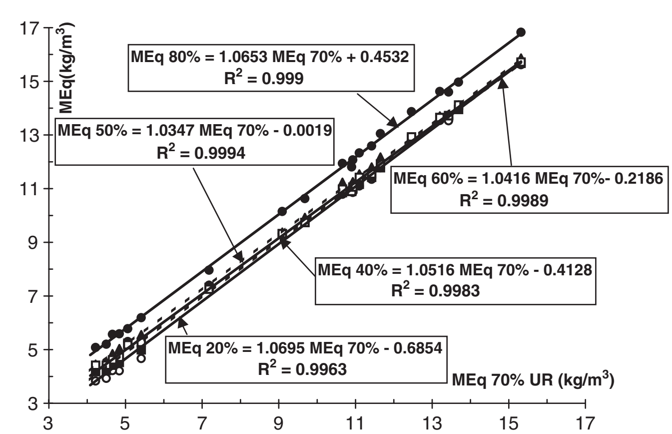

Fig. 1. Correlation of the moisture content at equilibrium (MEq) measured at different relative humidity (RH) values.