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Equilibrium relative humidity method used to determine the sorption isotherm of autoclaved aerated concrete

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ABSTRACT

The sorption isotherm of porous building material is basic information needed for the design and maintenance of materials. The equilibrium moisture content (EMC) method is used to determine this physical property. In this study, the equilibrium relative humidity (ERH) method was used to determine the adsorption data for autoclaved aerated concrete at seven temperatures and found that the ERH method could be used to determine the sorption data within a short time. Comparing with previous published data, no significant difference could be found at humidity >20%. Two different sizes of samples (small and large) revealed the same EMC data throughout the whole relative humidity (RH) range. The Oswin equation was the best ERH model for adsorption isotherm data. A temperature term could be incorporated into model for the adsorption data. Sorption isotherm data for other building materials could be determined with the ERH method.

1. Introduction

1.1. Background

The moisture properties of building materials are important in terms of heat transfer and moisture transport. In a fixed humid environment, materials could adsorb or lose moisture on the basis of the equilibrium state because of the balance in vapor pressure. There are two processes: adsorption and desorption. The relationship between equilibrium moisture content (EMC) and equilibrium relative humidity (ERH) at a fixed temperature is called sorption isotherm [1]. In building physics, the sorption isotherms data for porous building material are the basic information for the design performance of the thermal and hygroscopic properties [2].

There are methods used to determine the sorption properties: static volumetric method, dynamic column method and gravimetric method [3,4]. Static volumetric and dynamic column method require complex equipment and expense. The gravimetric method is the most common. The sample is placed in a container in an airtight environment in fixed temperature. When the weight of the sample is stable, the moisture content of the sample is the equilibrium moisture content. The saturated salt solution is usually used to maintain a constant humidity environment. Samples and their containers are placed under a temperature controller to maintain a set temperature. The high accuracy of an electronic balance is required to ensure the correlation of the moisture determination. Standard procedures of EMC determination for building materials have been proposed such as ISO 12751 [5] and ASTM C1498 [6]. The gravimetric method has been used widely in other area, such as food and agricultural products [7,8].

The gravimetric method is simple and inexpensive but time-consumption and laborious. The method requires several weeks for a material to reach an equilibrium state. Peuhkuri et al. [9] developed a rapid sorption method and found that the range and intervals of relative humidity and drying temperature have a significant effect on sorption isotherm. Kumaran et al. [10] noted the practical difficulties in determining of EMC of building materials with the ASTM standard C 1498. The factors included hysteresis effect, the dry state of reference, the moisture content, size and the history of the sample, the drying method and drying temperature.

Feng and his coworkers [11] discussed detail about the uncertainty sources in sorption isotherm measurement. Factors included drying with desiccant or an oven, sample size and crushed effect, exposure of different samples in different humidity environments at the same time, and the temperature effect. Four techniques were proposed to accelerate the determination periods: oven drying, small samples, placing different samples at different humidity

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environment at the same time and use an isotherm model that fits sorption data points.

Many sorption isotherm models have been proposed and reviewed for agricultural products [12,13], foods [14] and the ion sorption process [15,16]. Hamdaouia and Naffrechoux [17,18] evaluated the adsorption isotherms of two activated carbons, phenol and chlorophenols, with seven two-parameter, nine three-parameter and four four-parameter models. The correlation coefficients (r) and average percentage errors (APE) were selected as the criteria for evaluating the fitting ability of these models. The Guggenheim, Anderson, de Boer (GAB) equation was adopted to express the relationship of isotherm data for oriented strand panel [19] and high-performance concrete [20]. In a study of the sorption data for autoclaved aerated concrete (AAC), Feng et al. [11] evaluated seven models for their fitting ability with the criteria of the coefficient of determination (R^2), the residual sum of square (RSS) and the distribution of residuals [11].

Another method, ERH technique, has been developed to determine sorption isotherms of agricultural products and foods [21–25]. A similar concept has been used to measure the moisture content of building material [26]. A hole is drilled into the materials for measurement. The probe of an RH meter is then inserted into the hole, when the equilibrium of humidity and temperature in the hole is reached, the temperature and relative humidity of air enclosed in the hole is measured. The moisture content for the sample is calculated with the sorption isotherm model. For the ERH method to determine the isotherm data, samples with known moisture content are placed in a limited volume environment with fixed temperature. The RH of interstitial air is then detected. Detailed procedures are in the Materials and Methods section.

1.2. Objectives

The objectives of this study were to: (1) develop a rapid method to determine the EMC/ERH relationships for autoclaved aerated concrete (AAC) between 5 and 35 °C; (2) compare the sorption isotherms of AAC with previously published data; and (3) assess the fitting ability of ten adsorption isotherm equations.

2. Material and methods

2.1. Materials

The AAC is the popular building material used in tropic and subtropic regions. The advantages of this materials include good insulation, excellent acoustic performance, fire resistance no toxic and light weight. This material was chosen to be testing sample in this study. Two sizes of AAC samples, small and large, were chosen. Samples were cut from AAC blocks. The dimensions were 30 × 30 × 10 cm for small samples and 40 × 40 × 20 cm for large samples.

Prior to the experiment, samples were placed in an oven at 70 °C for two weeks to reach the dry state, rewetted by adding water to a pre-determined moisture content as described [27]. All samples were stored in sealed containers at 5 °C for six weeks to ensure the moisture equilibrium state.

2.2. RH meter

The THT-V2 humidity transmitter (Shinyei technology, Japan) was used in this study. The probe of the sensor consisted of an RH sensing element. The RH sensor was calibrated with several saturated salt solutions and the accuracy of the RH meter was 0.7% RH after calibration [28]. The reading value of RH meter was the independent variable and the standard RH value maintained by saturated salt solutions was the dependent variable. The calibration equation was a 3rd- degree polynomial equation. All measured RH values were transformed into actual values using calibration equations to improve accuracy.

2.3. ERH method

The set-up for the technique is in Fig. 1. Samples at known moisture content were placed in a plastic container, sealed to ensure airtight conditions, then placed in a temperature-controlled chamber that was fixed at 5 °C. The volume of the container was 650 ml and the volume of head space 50 ml. The temperature and RH meter were placed in the head space. When the temperature and the RH within the container were stabilized, the vapor pressure of samples and interstitial air in the container reached the equilibrium state. The RH and temperature values were recorded by the data logger. To ensure the equilibrium state, each temperature level was maintained for 12 h, then adjusted to next the next level. All ERH values were determined at seven temperatures (5, 10, 15, 20, 25, 30 and 35 °C). After completing the experiments, three samples were taken from each container to determine moisture content by the oven-drying method. The drying temperature was 70 °C for 72 h.

2.4. Sorption isotherm model

Nine sorption models were selected to evaluate the fitting ability of these sorption data. These equations are in Table 1: a, b, c and d are constant; M is moisture content (%, dry basis). RH is relative humidity in decimals. Mo, K and C are the parameters of the GAB model.

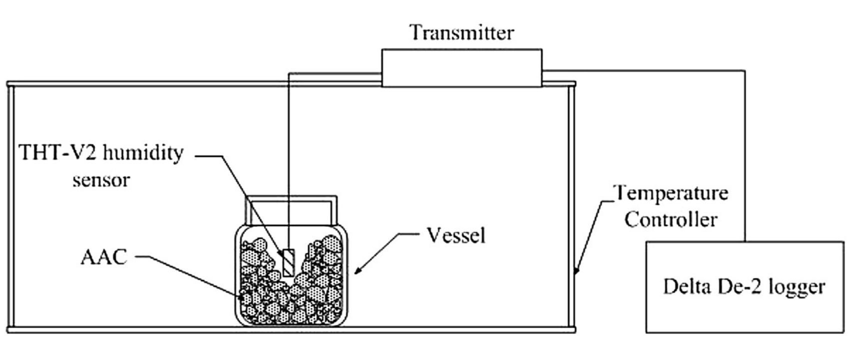

Fig. 1. The experimental set-up. The diagram of AAC and sensor was to show the placed position of sensor. The size and shape of the testing materials presented in this figure was not equal to the actual size of samples in this study.