



Equilibrium moisture content of earth bricks biocomposites stabilized with cement and gypsum



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ABSTRACT

In recent years, energy efficient and ecologically friendly buildings have been important in the housing and construction sector. One of the major barriers to producing good and useful products is the lack of detailed information about natural materials, in particular their moisture related properties, as these materials are hygroscopic and sensitive to moisture. This research aimed to determine the equilibrium moisture content of earth block materials, as an extremely important characteristic variable for all physical simulations. Earth bricks with different compositions were fabricated from cohesive soil, cement, and gypsum combined with two kinds of natural fibers. Wheat and barley straw were used as reinforcing fibers and materials were treated at various temperatures (10–40 °C) and relative humidity (33–95%). The moisture content was considered in dynamic equilibrium with the environmental conditions and the effects of relative humidity and temperature were investigated. The effect of relative humidity was observed more pronounced than that of temperature. The test results are discussed with reference to the relevance of the earth bricks as an ecologically friendly building material that is directly associated with the moisture related properties of buildings. The results also showed significant improvement in the durability.

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1. Introduction

Recycling of agricultural wastes present clear advantages from an economical point of view; the reduction of costs related to use of alternative raw materials; the reduction in consumption of virgin raw materials [1,2]. Natural fibers form alternatives for most widely applied synthetic fibers in composites technology and manufacturing. The interest in natural fibers comes about because they are cheap, light (providing better stiffness per weight), give more diverse markets for farmers, and reduce emissions of carbon dioxide and wastes going to landfill. Furthermore, natural fibers sources are renewable, they are green and environmentally friendly [3–5].

The deterioration of porous building materials is mainly due to the interactions between their structures and water. Depending on the material characteristics, physical state of water (liquid or

vapor) and environmental conditions, the quantity of water absorption and sorption mechanisms may be different [6]. In particular, the absorption of humidity from air, the capillary rise, the rain penetration, and water condensation phenomenon can lead to the formation of superficial moisture [7,8]. Earth bricks are experiencing a renaissance in sustainable buildings. When a hygroscopic material is placed in air, water molecules are constantly absorbed and desorbed to and from its surface depending on the air relative humidity. If the same number of water molecules are absorbed and desorbed, an equilibrium condition is reached. Because the material is neither gaining nor losing water, it is said to have reached equilibrium moisture content (EMC). When air remains in contact with the material for sufficient time, the partial pressure of the water vapor in the air reaches equilibrium with the partial pressure of the water vapor in the material. The EMC is a dynamic equilibrium and changes with relative humidity and temperature of the surrounding atmosphere.

Ashour [9] reported that the EMC value of wheat straw increases with increasing relative humidity and decreases with rising temperature. The relative humidity has greater effect on

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the EMC of straw bales than temperature. For straw bale, an EMC value of 15% seems to be safe, which corresponds to the water activity level or equilibrium relative humidity [10]. Ashour et al. [11] studied the EMC of earth plaster for straw bale buildings. The earth plaster was reinforced by wheat straw, barley straw and wood shavings. He found that, the maximum EMC was as less than 7% for different materials. The EMC value of a biological material can be reliably determined after exposing to an environment with constant temperature and relative humidity for an infinitely long period of time [12]. Damp crop stems are also more difficult to process due to their significant friction resistance force [13]. Moreover, moisture content above 18% promotes growth of fungi, which are present in wood and straw as spores, and may degenerate cellulose. When the moisture content is below 18%, fungi become dormant and when the moisture content exceeds a certain value, fungi may exponentially grow [14].

Furthermore, the deterioration of straw can also be due to microbial activities, such as growth, survival, death, sporulation, and toxin production of microorganisms. These activities are dependent on the environmental variables of temperature, pH, oxygen, radiation, and moisture. Moisture for microbial activity is measured as water activity, which is numerically equal to the equilibrium relative humidity. When the equilibrium relative humidity is kept below 70%, the microbial activity is largely suppressed and the straw remains stable [15]. Hydrophilic materials, such as wood, paper, and cotton stabilize the atmosphere against the changes in relative humidity through temperature variation and exchange of air with the surroundings [16]. The influence of temperature and humidity on the permeability is mainly determined by hygroscopic properties of materials, permeability to air flow, and their capillary transfer ability [17]. All building materials tested were susceptible to mold growth in humidity values of above 90% relative humidity at temperature above 15 °C [18]. In general, adsorption rate is dependent on both temperature and relative humidity [19,20].

There are several methods to determine the EMC. The most commonly used methods are static and dynamic gravimetric techniques [21]. In the static method, the sample reaches the EMC in still air moistened using various salt solutions, whereas in the dynamic one, the air is mechanically moving and often moistened with air conditioning units [22].

We conducted this research because of the shortage of information about the relation between earth bricks and the environmental conditions, particularly temperature and relative humidity. The moisture immigration from the environment into the earth bricks greatly affects the performance of the building elements, mainly walls. Reinforcement fibers were used to improve the strength and thermal insulation of the blocks. Cement and gypsum were used to improve the mechanical characterization of the blocks. So, the main objective of the current study was the establishment of the relationships between moisture contents of earth bricks and environmental conditions to obtain the sorption curves of earth bricks stabilized with cement and gypsum and reinforced with wheat and barley straw.

2. Materials and methods

2.1. Materials

In this investigation, four different materials were used, including cohesive soil, cement, gypsum, and agro fibers. The composition of the cohesive soil texture was 28.7% clay, 63.3% silt, 3% gravel, and 5% sand. The particles sizes were <0.002, 0.0033, 0.172, and >2 mm for clay, silt, sand, and gravel, respectively. Two different types of fiber, wheat and barley straw, were used as reinforcement. The average straw length was approximately 4 cm.

2.2. Sample preparation

Initially, oversized gravels and organic matters (grass roots) were removed from the natural cohesive soil. The soil samples were dried at a temperature of 105 °C to obtain the dry constant weight. The natural fibers were also oven dried at 105 °C to a constant weight.

A variety of earth brick samples with various compositions containing cohesive soil, cement, gypsum, and fiber were fabricated. The amounts of materials were determined as their dry weights. The raw materials of soil, cement, gypsum, and fiber were placed in a mechanical mixer and dry blended for about 20 min until they were homogeneously combined. Afterwards, water was sprayed over the mixture until 24% moisture content level was achieved. The materials were again blended using an electric mixer for approximately 30 min until a homogenous mixture was obtained (Fig. 1).

Earth bricks from different mixtures combined with two types of natural fibers used in the sorption tests are listed in Table 1. The material compositions in Table 1 are given as a percentage of dry weight for earth ingredient.

The soil-fiber mixture was then poured into a wooden mold. The wood mold dimensions were $4 \times 4 \times 2$ cm. The surface was leveled and compressed using a loading plate under a force of about 50 kgf. After pressing, the samples were allowed to dry slowly to avoid cracking. The samples were dried under controlled room conditions for 60 days. The average temperature and relative humidity inside the laboratory room throughout the drying process were 21.7 °C and 56.1%, respectively.

2.3. Examination method

The EMC test was conducted according to DIN EN ISO 12271 standard method [23]. The samples were placed on a wire mesh over a plastic box containing various saturated salt solutions, as presented in Table 2. The samples together with the wire mesh and box were put in a closed box. These boxes were placed inside a climate chamber at various temperatures (10, 22, 30, and 40 °C) and relative humidity levels (33%, 51%, 75%, and 90%). For each recipe and humidity level, three samples of the same materials were used as replicates. In total, 54 samples for each material were fabricated and examined.

The climate conditions inside the box were monitored with combined T/RH sensors. After 3 to 4 weeks, when constant relative humidity inside the box was achieved, the samples were weighed and the moisture contents were calculated.

A climate chamber was used for the storage of the baskets under controlled temperature. The measured signals were directly



Fig. 1. Electrical mixer used for mixing different materials.

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