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The influence of two crop by-products on the hygrothermal properties of earth plasters

M. Palumbo [a,*], F. McGregor [b], A. Heath [c], P. Walker [c]

[a] Barcelona School of Building Construction, Applied Physics Dept., UPC Tech, Barcelona, Spain
[b] LGCB-LTDS, UMR 5513 CNRS, ENTPE, Université de Lyon, 69100 Vaulx-en-Velin, France
[c] Department of Architecture and Civil Engineering, University of Bath, Bath BA2 7AY, UK

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ABSTRACT

The incorporation of natural fibres in earth construction elements is a common practice that is found both in traditional and in contemporary building systems. The positive effect that such materials have on the mechanical properties of the clay mixtures has been established in previous research. However, their effect on the hydric and thermal properties is less well understood and these properties are important for thermal mass and passive humidity control in buildings, aspects linked to occupant health and reductions in energy use. The present paper includes the first in-depth study of the thermal conductivity and diffusivity, as well as the water vapour permeability and moisture buffering of compressed earth blocks and plasters incorporating natural fibres. Two different vegetable materials, barley straw and corn pith, were mixed to the clay materials in two different percentages (1% and 2%). The results show that the vegetable materials have a great impact on the thermal properties and the apparent density of the mixtures, but a limited effect on the hydric properties. The greatest improvement of the moisture behaviour was shown by the specimens incorporating 2% of corn pith. This improvement is greater for short time exposure than long time exposure. After 3 h, these mixtures adsorbed 15.5 g of moisture more than the plain samples, but after 8 h the difference was reduced to 8.0 g. This indicates that such mixtures might be more appropriate in environments with short and intense moisture loads, such as bathrooms. Previous research has demonstrated that earth provides the highest moisture buffering capacity of common building materials, and this research demonstrates how these properties can be enhanced for specific applications.

1. Introduction

A common practice in earth building construction is to add natural fibres to the soil. Typical examples are adobes, cob in the south-west of England or terre/paille and bauge in France. Adding fibres to the soil have several advantages: first, they reduce shrinkage cracks, which is particularly important for plasters; second, they increase the compressive strength; and finally, they improve the thermal insulation properties [1–5]. The addition of fibres has been reported to influence the equilibrium moisture content and the dynamic moisture buffering properties but little information is available determining the extent of such influence, which is highly dependent on the kind of fibre added to the plaster.

Lima and Faria [6] analysed six different clay mortars in which oat straw fibres or typha fibre wool had been added in different proportions. Their results indicate that the addition of fibres has little influence on the moisture adsorption and desorption of the plasters. In a study conducted by Ashour et al. [7] three different fibres were added to a soil for the preparation of earth plasters. The fibres consisted of wood shavings, wheat straw and barley straw. The barley straw showed the strongest influence on the equilibrium moisture content. The increase in equilibrium moisture content for a relative humidity (RH) between 40% and 80% was in order of 1%–3% towards the higher RH levels. In Maddison et al. [8], samples of clay plasters mixed with cattail's wool (Typha) and chips of cattail and reed (Phragmites) were subjected to a sudden change in RH from 50% to 80% in order to compare their moisture sorption capacity. The mixtures incorporating the fibres showed an enhanced moisture adsorption up to 24.5% after 12 h of exposure. However, the kinetics of moisture sorption was dependant on the kind of

* Corresponding author.
E-mail address: mariana.palumbo@upc.edu (M. Palumbo).

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fibre incorporated. The addition of cattail wool resulted in the most significant increase of moisture adsorption after 1 h. However, the moisture adsorbed after 12 h was similar or even lower than plain samples. On the other hand, the addition of cattail chips had a lower effect on the moisture absorption after 1 h, but presented the best results after 12 h.

This increase in EMC which in turn modifies the moisture capacity of the material could have a beneficial influence on the dynamic moisture adsorption or moisture buffering capacity. The moisture buffering capacity of a material is related with its ability to moderate variations in the relative humidity of its surrounding environment. High indoor air relative humidity causes discomfort and might lead to low indoor air quality, as it is related with the propagation of biotic hazards such as moulds and dust mites [9]. Low air relative humidity causes dryness of the mucous in the respiratory tracts and discomfort. In homes, high air humidity is usually the limiting factor determining the minimum sanitary ventilation rates. The control of moisture extremes has positive effects on indoor air quality and might enable a reduction in the ventilation rate and thus, a reduction in heat loses due to air renovation [10–12]. In the frame of the NORDTEST Project [13] and the Japanese Industrial Standard JIS A 1470-1 [14], a useful index was introduced to quantify the moisture buffer capacity of a material in conditions of surrounding humidity variation. The Moisture Buffer Value (MBV) indicates the amount of water vapour that is transported in or out of a material, during a certain period of time, after a controlled variation of relative humidity on one face of a sample. Such an index is included in the international standard ISO 24353 [15].

The water vapour permeability and the thermal conductivity and diffusivity are other material properties that play a role in moist related indoor air quality. These properties have influence on the risk of interstitial condensations, which results in health problems and causes damages on the building structure. They also affect the quality of the thermal envelope, which. has been found to be too a driven factor for the propagation of moulds and dust mites in indoor environments [9].

The effect of bio-based materials in the water vapour permeability and moisture buffering capacity of clay building materials was investigated in this study using a series of compressed earth blocks and earth plasters. Earth blocks were prepared with variable contents of barley straw fibres, while earth plasters were also prepared with the addition of a varying content of barley wool and corn pith granulate. In particular, the experimental work was focused on determining how the composite properties were affected by the combined effect of the addition of vegetable materials, the nature of soil composition and the manufacturing process. It was anticipated that the fibres would increase vapour permeability as well as moisture capacity by transferring moisture along fibres on the soil/fibre interface and through the body of the fibres. In the case of the granular materials, it is possible that a similar effect is observed, due to the high hygroscopicity of the fibres compared with granular aggregates and to the fact that their incorporation results on a significant reduction of the bulk density of the mixtures, thereby providing more available volume for water to fill. However, it was uncertain to what extent this effect was going to occur and how the fibres would affect the evolution of the moisture buffering capacity by time, i. e. the short and long term moisture sorption.

2. Materials

The organic materials used in this study were barley straw fibres shredded to two different fibre lengths and corn pith aggregates. Barley straw was unbaled and ground. Part of the straw broke down into short and fine fibres that were sieved through a 0.5 mm diameter sieve. Part of the straw just broke longitudinally forming longer fibres that tended to tangle together in a woolly ensemble. Both shapes (short and long fibres) were used. Corn stalks were harvested and dried at room temperature for a week. Then the external peel was manually removed and the corn pith was ground and sieved to 1.0 mm size. The macrostructure of these materials is shown in Fig. 1.

Moreover, barley straw and corn pith also present important differences regarding their microstructure, which is clearly visible on SEM-images (see Fig. 2). Barley straw is formed by a mixture of parenchymatic cellules and several vascular bundles of fibrous structure. The total thickness of the cellular wall and the plasma membrane of the parenchymatic cellules is about 0.6 μm, with an intercellular space of diameter about 3 μm. On the other hand, corn pith is mainly formed by parenchymatic cellules, as the vascular bundles are removed with decortication. This fact explains that shredded particles are fibrous shaped in the case of barley and granular in the case of corn pith. The cellules of corn pith are larger, with thinner walls and bigger intercellular spaces, which results in a higher macro-porosity [16].

The soil used for the plasters and the compressed earth blocks (CEB) differed in its composition. The soil used for the plasters was obtained from a commercial earth plaster available in the UK. It was composed by 20% of a fine fraction of clay and silt, 74% of sand and 6% of gravel. The soil used for the CEB was artificially prepared in the laboratory with a ground commercial kaolinite to form the clay sized portion, silt obtained from the sieving of an available soil and commercially available silica based sand. The mixing proportions to obtain a coherent sample were 25% of clay, 20% of silt and 55% of sand. The soils where analysed with x-ray diffraction in order to obtain the chemical composition of the fine and coarse fractions. This is presented in Table 1, together with the maximum particle size of the coarse fraction and the Atterberg limits corresponding to the fine fraction. The particle size distribution and the aspect of the gravel fractions of both soils are presented in Fig. 3.

2.1. Sample preparation

Cylindrical compressed earth blocks (CEB) samples of 100 mm diameter and 30 mm thickness where prepared in a plastic sewage pipe used a formwork and compacted with an adapted Wykeham Farrance 50 kN triaxial frame. Two different compaction methods were used as it was considered that the addition of straw was very likely to change compaction behaviour. The first method consisted on compacting the samples to a certain volume with known dry mass to obtain the same dry density of 1800 kg/m^3 for each sample (code sd). The second method used a maximum compaction force (of 4.9 kN) in order to identify the influence of adding fibres in a real situation where the compaction force or energy remains constant and the final volume is not controlled (code sc), as with standard test procedures for cohesive soils [17]. The plain sample was compacted at the optimum water content according to EN 13286-2:2010 and the samples with added fibres had additional moisture added until the consistency of the uncompacted material was similar to the plain sample, as determined by visual inspection. As shown in Table 1, no significant difference was observed between the final density of the specimens prepared to reach equal apparent density (sd) and those compacted with an equal compaction force (sc) and it was not possible to achieve the desired density of 1800 kg/m^3 for some of the sd samples as the force required to achieve this was beyond the capability of the compaction equipment. CEB samples containing 0%, 1% and 2% of barley straw were prepared in triplicate using both compaction methods.

The plaster specimens of 100 mm diameter and 20 mm