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Hygrothermal properties of clayey plasters with olive fibers

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HIGHLIGHTS

- Earthen samples, containing different percentages of olive fibers, were tested.
- Hygrothermal functional properties were characterized.
- The ability of the material to exchange moisture was studied by calculating the ideal Moisture Buffering Value (MBV_{ideal}).
- The results achieved from the test measurements show that the addition of olive fibers resulted in an increase of porosity.
- The moisture content adsorbed increased especially for the specimens with higher content of fibers.

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ABSTRACT

This research deals with how to use agricultural waste materials in constructions considering that the development of innovative materials has to respond to both environmental and energy issues. The leaves and the small branches derived from the pruning of olive trees were incorporated, after drying, into a clay-sand mixture to obtain a bio-based plaster. Earthen samples, containing different percentages of olive fibers, were prepared and tested to investigate their hygrothermal behaviour. Thermal conductivity and the effects of several parameters on thermal performance were analyzed. The evaluation of the hygric behaviour was based on the measurement of the water vapour diffusion resistance factor and of the isothermal sorption curves. Results showed that the addition of olive fibers in the earth matrix enhances the insulating and hygric performances. The ability of the material to exchange moisture was studied by calculating the ideal Moisture Buffering Value (MBV_{ideal}). Results showed that the effects of moisture adsorption/desorption improved with the increase of the fibers content.

1. Introduction

Considering the development of society and people's ecological awareness, a sustainable and healthy indoor environment is increasingly attracting the attention of the research. Thus, renewable and environment-friendly materials are highly demanded [1]. Particularly, in recent years, there has been a revival of interest in earthen construction materials. The main advantages of the use of earth are related to the significant reduction in environmental impact. Clay is an abundant local resource with very low embodied energy, which is cheap and easy to work [2]. According to Aymerich et al. [3] earth-based materials can also offer very high levels of thermal comfort due to their high humidity absorption/desorption rates, heat storage capacities and sound transmission properties. Natural fibers are added to the mix, enhancing the physical performances as the reduction of density. It is important to underline that the fibers are renewable and they have a sustainable life cycle [4].

This study investigates hygric and thermal properties of the clay-based plasters incorporating natural fibers as olive pruning waste. According to Meli et al. [5], earth plasters outperform conventional industrial plasters. On one hand, producing plasters from unbacked clay and sand requires a relatively small amount of energy compared to that required to produce conventional lime and cement plasters, since the production of these materials requires very high temperatures. On the other hand, transport represents an important proportion of the overall impact of earth plasters. Clay can be considered a local source available on the same site in which building will be realized.

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Clay plasters are especially suitable for interior surfaces, to create comfortable and healthy spaces with a minimal impact on the environment. Many studies deal with the use of natural fibers as replacement to synthetic fibers in reinforced composites. Several aggregates derived from plants such as coconut fibers [6], hemp [7], straw [8], flax fibers [9], date palm trees fibers [10], or bamboo [11] have already been studied due to their attractive features, such as good mechanical properties, low cost, low density, low thermal conductibility, durability and recyclability. Radazzo et al. [12] carried out specific laboratory tests on commercially available pre-mixed earthen plasters. The aim of the research was to verify how mineralogical and textural features might affect the performances of the final products in terms of moisture absorption and thermal conductivity. Results showed that the thermal conductivity was strictly connected to the grain shape, grain size and porosity. Moreover, the most significant increase in moisture content occurs for the mixtures characterized by a higher amount of fibers.

Palumbo et al. [13] evaluated the thermal conductivity, the thermal diffusivity, the water vapour permeability and the moisture buffering of plasters incorporating two types of vegetable materials such as barley straw and corn pith. It was observed that the thermal conductivity of the clay materials decreased with the addition of the vegetable fibers due to the reduction of density. The incorporation of corn pith caused the most significant reduction of thermal conductivity. The vegetable materials had a limited effect on the hygric properties. They provoke a moderate increase of the water vapour permeability and the moisture buffering capacity. Ashour et al. [14] measured the thermal conductivity of three different types of fibers as a reinforcement for natural plasters. Wheat straw, barley straw and wood shavings were used. As expected, the thermal conductivity of all materials decreased with increasing fibers content and increased with the addition of sand. The results demonstrated that the plaster reinforced with barley straw fibers had the lowest values of thermal conductivity. Plasters with wood shaving fibers had the lowest values of thermal insulation due to their highest density.

Currently hemp fibers are the most used for sustainable construction materials. Mazhoud et al. [15] investigated hygric and thermal properties of two hemp-lime plasters with different sizes of hemp shiv. Results showed that the hemp-lime plaster with the smallest hemp shiv was the best hygric regulator. The fiber size was also the basis of the studies conducted by Benmansoura et al. [16]. They investigated mortars formed with sand, cement and different sizes of date palm fibers. The addition of fibers in the mortar matrix decreased its density. Therefore, the first advantage of the use of natural fibers was the decreasing of its thermal conductivity. On the other hand results showed that the thermal conductivity increased with water adsorption. The date palm fibers showed an enormous capacity of water absorption and the finer fibers adsorbed more water than the larger fibers, showing the higher thermal conductivity values.

2. Experimental procedure

2.1. Materials

Four different clayey plasters with olive fibers were studied. Different percentages of clay, sand, gravel and fibers were used. The composition of the cohesive soil is as follows: quarry fines, quartzite grit sand (<2 mm), quartzite grit gravel (2–4 mm), hydrated lime and water.

The clay used has sandy fraction (1%), silt (28%) and clay (71%). Carbonates were equal to 22%. The clay granulometric analysis is shown in Fig. 1.

The porosity of the clay and the fibers (olive leaves and branches) was measured by a Helium gas Pycnometer ULTRAPYC 1200-e Quantachrome; the results are shown in Table 1.

The microstructural morphology and chemical composition of the used clay and of the clayey olive plaster were characterized by Zeiss EVO MA 10 Environmental Scanning Electron Microscopy (SEM) with Oxford Instruments Inca model spectrometer for Energy Dispersive X-ray Spectrometry (EDS). Fig. 2 shows the scaly crystal structure of the clay, whereas Fig. 3 shows the microstructural morphology of the plaster.

EDS (Energy Dispersive Spectroscopy on the SEM) was used to identify the main elemental composition: Figs. 4 and 5 represent the spectrum of clay and clay-olive plaster, respectively.

Clay exhibited a higher content of SiO_2 than the clayey plaster (Figs. 4,5), in fact in the first case the SiO_2 content was on average around 33.62% and in the second case was on average around 41.70%. This is likely due to the higher sand content in the mixture.

Clay, sand and gravel were mixed with leaves and branches derived from the pruning of olive trees. According to Laborel-Préneron et al. [17], the aggregates were sized to obtain a homogeneous mixture that would be easy to apply on the wall. The average size of the fibers was about 2 cm as it is shown in Fig. 6.

The SEM was also used to analyze the microstructural morphology of an olive leaf. Fig. 7 shows that the olive leaf appears covered by numerous starred petals that guarantee ultraviolet radiation protection and maintain a thin layer of damp air to the surface.

Table 1
Porosity and true density of the clay and the olive pruning waste.

Raw materials	True density ρ_{true} [kg/m^3]	Porosity n [-]
Olive waste	1251	0,23
Clay	2859	0,37

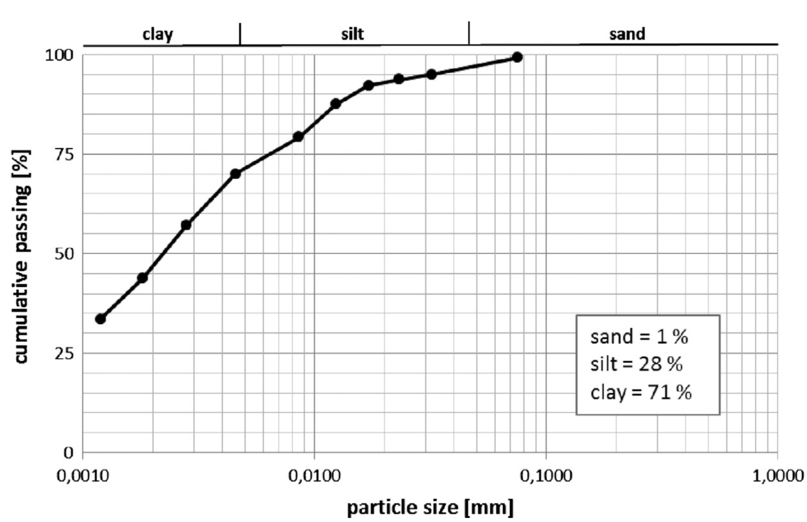

Fig. 1. Granulometric analysis of clay.