Influence of fiber crushing on light earth hygrothermal properties

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Abstract:
Present study aims to evaluate the effect of fiber crushing on the structural and hygrothermal properties of light earth. For this purpose, reed fibers were treated differently and incorporated in the light earth. The fibers were first cut, then partially crushed. After that, crushed and uncrushed fiber were mixed into a clay soil. The obtained light earth samples were structurally and hygro-thermally characterized. Fiber grinding showed a decrease in the light earth hygrothermal properties, including thermal conductivity, sorption, and water vapor permeability. This was assumed due to the change in porosity.

Keywords:
Light earth, Fiber crushing, Porosity, Hygrothermal properties, Building insulation.

1. Introduction

In the context of the global energy transition, several approaches are being explored to reduce the energy consumption and carbon footprint of buildings without compromising occupant comfort. Some researchers are attempting to improve the thermal performance of the walls without disturbing the building envelope by using heat storage system (ALASSAAD *et al*., 2021, ANGO, 2011) or adding insulation layers (ZACH *et al*., 2013). Otherwise, new innovative solutions targeting building wall improvement have begun to emerge, mainly in concrete. It involves adding components to the cement matrix which can enhance the thermal behavior, such as foaming to increase the voids in the concrete (RUIWEN, 2004) or including light aggregates (CHIDIGHIKAOBI, 2019, NGUYEN *et al*., 2014, YUN et al., 2013). The porosity offered by the foam or lightweight aggregates decreases the thermal conductivity of the concrete as a function of their dosage in the mix. In compliance with thermal and environmental regulations,

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the well-known earth construction techniques (adobe, cob, light earth, etc.) have been revised. So many investigations have been undertaken for a better understanding of earth-based materials thermal, hygroscopic and mechanical behavior, in order to find an innovative solution limiting energy consumption (COLINART *et al.*, 2020, GOODHEW *et al.*, 2019, HAMARD, 2017, HOLZHUETER & ITONAGA, 2017, LABOREL-PRÉNERON *et al.*, 2016, PHUNG, 2018). The use of earth-based materials in construction is a true alternative. Earth is a naturally occurring resource that is often widely available. Most earth that contain clay can be used for construction (HOUBEN & GUILLAUD, 2006). Materials from renewable raw materials (such as plant materials) are an answer to the problem of depletion of natural resources. Together with recyclable materials (such as earth), these materials provide an answer to the problem of waste at the end of the building's life. Earth-based materials are characterized by their good thermal mass and capacity to regulate the buildings hygrometry with a low economic and environmental cost. It retains or releases moisture in the air in accordance with the ambient humidity, contributing to a healthier indoor environment (ANGER *et al.*, 2011, CAGNON *et al.*, 2014, GIUFFRIDA *et al.*, 2019, MEDJELEKH *et al.*, 2017, TOURÉ *et al.*, 2017, ZHANG *et al.*, 2020). This natural moisture regulation is a quality missing in conventional building materials such as concrete. Many studies have been carried out to improve the thermal properties of earth-based materials. For example, the density impact on the hygrothermal properties of earth-based materials has attracted particular interest (CAGNON *et al.*, 2014, COLINART *et al.*, 2020, LABAT *et al.*, 2016, MEDJELEKH *et al.*, 2017, NIANG *et al.*, 2018, PHUNG, 2018, PHUNG *et al.*, 2019). Furthermore, these studies have demonstrated the effect of fiber type and shape on density, porosity and subsequently on hygrothermal properties. Present study aims to evaluate the effect of fiber shape on porosity and hygrothermal properties. For this purpose, reed straws were processed differently. One part is simply cut into length of 4 cm keeping the straw aspect, the other part is cut but also crushed. These straws are used in a mixture of light earth for thermal insulation purposes.

2. Earth-based material preparation

Present study was inspired by the CobBauge research project in which different formulations were tested. Thus, the most thermally efficient earth-fiber mixture, reported within the project, was selected (DOCUMENTATION TECHNIQUE, 2018). Thereby, the material mix is composed of silty-clay earth and 25 % wt. of reed.

As for soil characterization, plasticity, consistency and clay content were determined based on the Atterberg limits and the methylene blue value (MBV) according to the standards NF P94-051 (NF P94-051, 1993) and NF P94-068 (NF P94-068, 1998), respectively. The limits (liquidity limit (LL) and plasticity limit (PL) serve as an indicator of an earth's plasticity by giving the plasticity index (PI). The methylene blue test offers an indicator of the clay content and reveals the clay's activity. Results of soil characterization are given in Table 1. Soil classification is performed based on conventional geotechnical analysis and considering the applicable standards. Besides, the grain size distribution was investigated following the standard XP P94-041 (XP P94-041, 1995). The methylene blue value and grain size distribution allow the soil classification as sandy, silty, or clayey.

Table 1. Soil characterization.

Parameter	***Soil distribution [%]***		***LL [%]***	***LP [%]***	***PI [%]***	***MBV [g/100g]***
	Particle size (<2 mm)	*Particle size (<80 µm)*				
Soil	*100*	*95*	*57.8*	*42.5*	*5.64*	*15.3*

As mentioned in the introduction, the fibers are processed differently. Both fibers are cut at 4 cm, but a part is then crushed. Fibers aspect is shown in Figure 1.

Figure 1. Aspect of fibers before and after crushing.

The formulation *i.e. each dosage*, is defined according to the mass of soil mass. 25 % mass of fiber and 100 % mass of water is added. Water is added first. With this amount of water, the earth gets to its liquid state. Then, the fiber is added and mixed for about 2 min. The mixing procedure is carried out within a concrete mixer (PROVITEQ Concrete Mixer 65 L). The molds are filled and placed in an oven at 40 °C. Characterization of the prepared samples begins when the samples are dry. Table 2 summarizes the performed tests, the standards met, the size, and the number of samples tested.

Table 2. Standard, number, and size of samples for testing.

Test	***Standard***	***Sample dimensions [cm]***	***Number of samples***
Moisture sorption isotherm	*(NF EN ISO 12571, 2013)*	*3x3x3*	*3*
Water vapor permeability	*(NF EN ISO 12572, 2016)*	*Ø15x5*	*3*
Thermal conductivity	*(ISO 8301, 1991)*	*22x22x4*	*3*
Porosity	*(NF ISO 5017, 2013)*	*Ø11x3*	*3*

3. Experimental method

3.1 Porosity

Porosity is an essential physical parameter in material characterization. According to the NF ISO 5017 standard (NF ISO 5017, 2013), this parameter can be measured by immersing small samples in a liquid, here it is a non-wetting oil, dearomatized oil.

The samples undergo vacuum saturation in a desiccator for at least 24 hours, allowing the liquid to replace the air in the pores without interacting with the sample. Then they are weighed with the oil and then weighed in air. Finally, the samples are oven-dried at 105 ± 5 °C. This allows the knowledge of porosity volume initially filled with oil. The accessible porosity p_0 is given by:

$$p_0 = \frac{M_{air} - M_{dry}}{M_{air} - M_{oil}} \quad (1)$$

where M_{dry} is the mass of dry specimen, M_{air}, the mass of saturated specimen in air and M_{oil}, the mass of saturated specimen in oil. Light earth, like all hygroscopic materials, is known to have a significant impact on building's interior air quality and energy consumption. In the following section, light earth hygrothermal properties are described along with the methodologies used to study them.

3.2 Hygroscopic behavior

The first step is the study of the interaction between light earth and moisture using the Dynamic Vapor Sorption technique (ProUmid SPSx-1µ). This equipment offers accurate monitoring of sample mass and sorption kinetics with a precision balance and careful temperature and humidity control. In this study, sorption isotherms of raw materials (earth and fibers) and mixtures are examined according to the standard ISO 12571 (NF EN ISO 12571, 2013).

The pre-dried samples were exposed to an environment with relative humidity varying from 10 % to 90 % in 5 steps while keeping the operating temperature constant at 23°C. Afterward, the dry cup method is used to study the capacity of a material to let water vapor pass through. This property called water vapor permeability was measured according to the standard ISO 12572 (NF EN ISO 12572, 2016). The mass tracking of the sample is done under a humidity gradient (0 % RH inside, 50 % RH outside). Measurements of water vapor permeability by the dry cup method provide insight into the material's behavior when moisture transfer is dominated by vapor diffusion. The influence of type of fibers used on the hygroscopic behavior of earth-fiber mixtures can be assessed by determining moisture sorption isotherms and water vapor permeability.

3.3 Thermal conductivity

Thermal conductivity is an important parameter to consider when developing a building’s insulating materials. This parameter characterizes the ability of a material to conduct heat from a hot spot to a cold one. In this work, it is measured with a Heat Flow Meter HFM 436 Lambda using Fourier’s law (GOOCH, 2011) and used for calculation. The measurements were performed at 14 °C, 24 °C, 34 °C with a temperature difference between the two sides of the samples fixed at 10 °C.

4. Results and discussion

4.1 Porosity

To observe fiber's porosity, scanning electron microscopy technique has been used. From SEM images reported in Figure 2, it can be seen that crushed and uncrushed fibers present relatively the same structure. However, the grinding degrades slightly the fibers pores in the different layers and destroys cavities, see Figure 2. Crushing induces a slight light earth porosity variation.

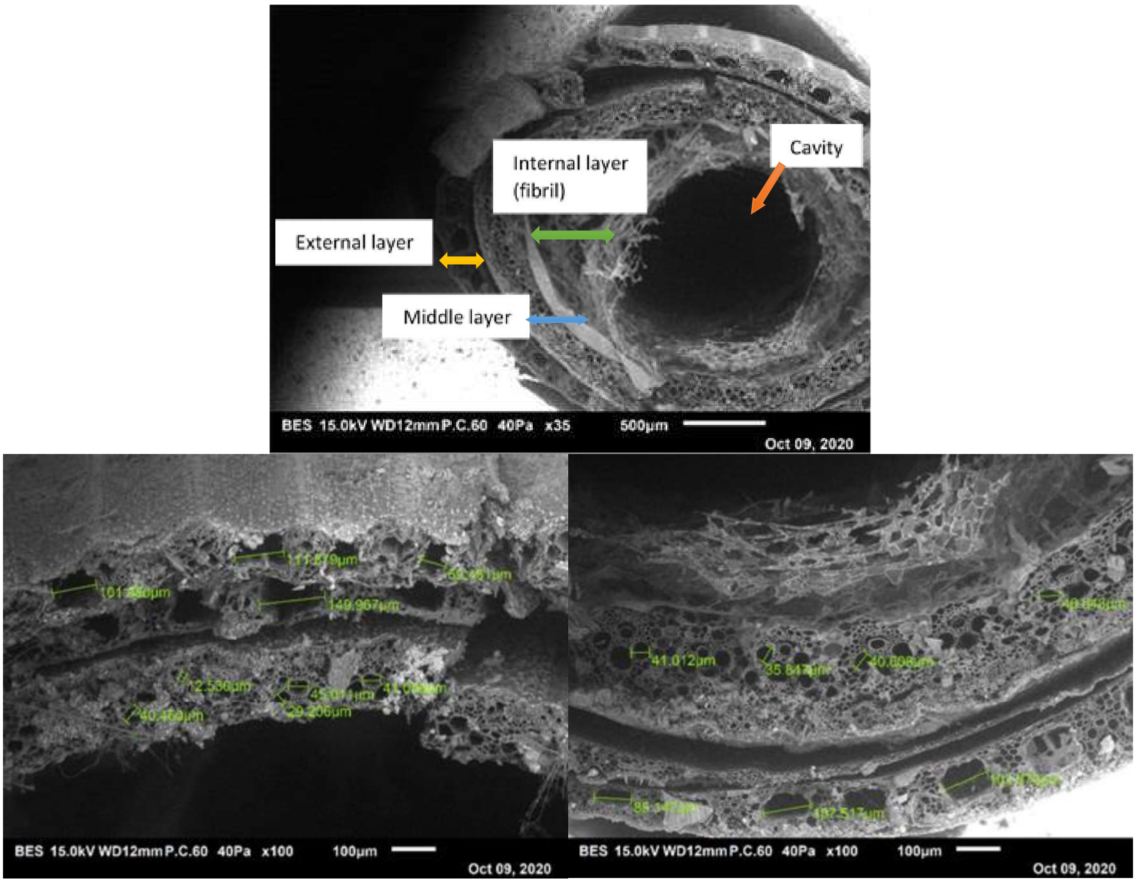

Figure 2. MEB image of crushed (right) and uncrushed fiber (left).

As it can be seen in Table 3, light earth with uncrushed fibers is more porous than the one with crushed fibers. Furthermore, this decrease in porosity will surely impact the hygrothermal behavior of the light earth.

Table 3. Light earth porosity when crushed and uncrushed fibers are incorporated.

Fiber used	***Crushed fiber***	***Uncrushed fiber***
Porosity [%]	*54*	*58*

4.2 Hygroscopic behavior

In present study, two hygroscopic properties have been studied. The first one is related to the material's ability to adsorb/absorb moisture (sorption). This property is directly linked to the material's constituents. In present work, light earth constituents are kept unchanged. Consequently, regarding its sorption behavior, no significant change will be held. This assumption is confirmed with the results obtained experimentally, see Figure 3. However, water vapor permeability is largely affected by porosity as moisture seeps through the pores. The light earth's water vapor permeability decreases, and its water vapor resistance increases when the fibers are crushed, see Table 4. This slight resistance increase is supposed due to the small reduction in porosity.

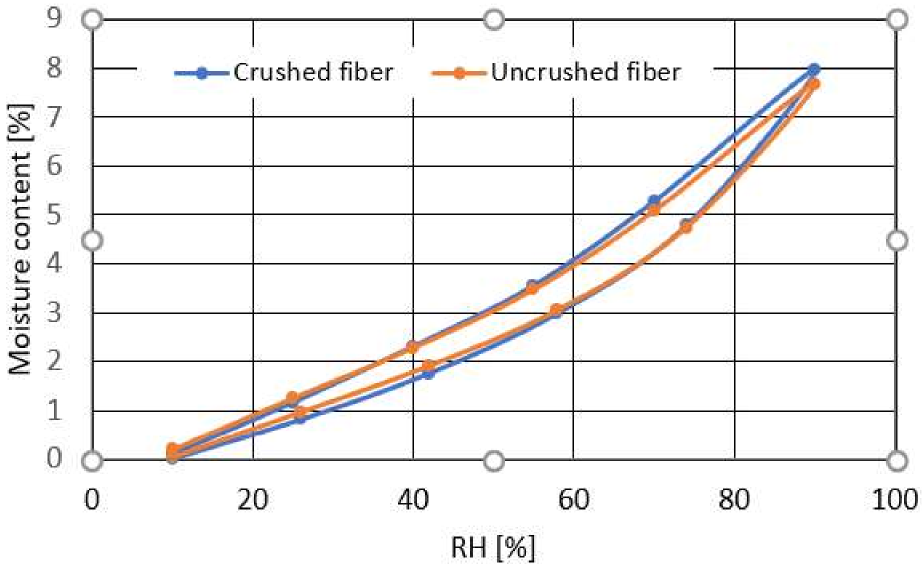

Figure 3. Moisture sorption isotherm of light earth when crushed and uncrushed fibers are considered.

Table 4. Water vapor resistance factor of light earth when crushed and uncrushed fibers are considered.

Formulation	***Crushed fiber***	***Uncrushed fiber***
Water vapor resistance factor μ	*7,237*	*7,101*

4.3 Thermal conductivity

Materials thermal conductivity depends, among others, on the constituent nature, their density as well as porosity. With the decrease of porosity, the mixture loses air-filled pores and consequently insulating properties are affected. When the fibers are grinded, the porosity decreases, and the thermal conductivity increases. As a result, light earth loses approximately 23 % of its thermal conductivity, see Figure 4.

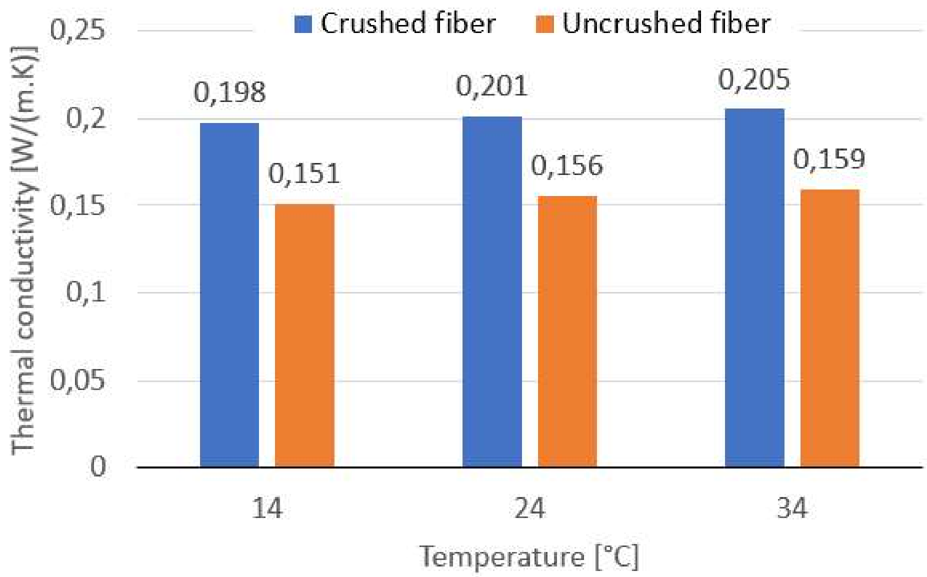

Figure 4. Thermal conductivity of light earth at three different temperatures.

5. Conclusion

In present study, we were interested in the effect of fiber crushing on light earth thermal and hygroscopic properties. Samples with different cut and/or crushed fibers have been prepared. Thermal conductivity, sorption behavior, and water vapor permeability have been experimentally studied. Regarding thermal properties, the study showed that light earth thermal conductivity increases when the fibers are crushed. This is supposed due to the decrease in the material's porosity resulting from the fiber crushing. The fiber crushing has also affected the light earth water vapor permeability. Nevertheless, the sorption behavior does not change since the mixture constituents have been kept unchanged.

6. References

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