# Experimental Investigation on the Influence of Partial Immersion and Drying Cycles on Hemp Concrete Properties

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**Abstract.** The construction sector has a significant environmental impact, since it is the largest energy consumer and is responsible for 25% of greenhouse gas emissions. Vegetal concretes represent a good alternative to reduce the environmental footprint of building materials, because of their thermal insulation properties and the use of vegetal waste. In addition, they have the outstanding environmental quality of being carbon negative. Hemp lime concrete is the most used bio-based material in building sector and its potential as an environmental-friendly material was quickly realized. It is a relatively new building material and its use is limited by the lack of data concerning its durability and the evolution of its properties over time.

This paper focuses on the influence of an accelerated aging of hemp lime concrete on its hydric and thermal properties. Samples will undergo several cycles of partial immersion and drying and will be characterized before and after the accelerated aging. Partial immersion was preferred to complete immersion, as it is more representative of the real climatic conditions. The thermal conductivity and the capillary absorption coefficient will be determined. Microscopic observations of the surface topology will also be carried on, in order to evaluate the microstructure alteration.

**Keywords:** Hemp lime concrete · Durability · Partial immersion and drying · Hygrothermal properties

## 1 Introduction

Construction sector is a huge energy consumer and is responsible for a large amount of $CO_2$ emissions, thus becoming a source of concern. This is mainly due to the poor thermal insulation of buildings that requires higher energy demands and therefore generates more greenhouse gas emissions. Bio-based materials have proven to be more efficient in terms of thermal and hygroscopic properties, compared to usual insulation materials. Indeed, they offer many advantages concerning energy needs, thermal comfort and environmental impact as they also allow reducing the carbon footprint [1–3].


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Bio-based materials are increasingly used in the construction sector, as they have interesting hygrothermal and acoustic properties [4, 5]. It is generally composed of vegetal aggregates, called shiv particles, coated by a mineral binder, usually based on lime in order to maintain the hygroscopic properties of the resulting material.

Hemp concrete is one of the most used bio-based materials in the construction sector. It has interesting thermal and phonic insulation performances and moisture regulation properties that works as a moisture buffer [6–8].

The evolution of the properties of hemp lime concretes is highly dependent on the climatic conditions to which they are exposed. Indeed, bio-based materials are highly affected by relative humidity, temperature and liquid water, as they can cause swelling, chemical reactions and microstructural variations [9]. Recently, studies were interested in durability of hemp concrete, through accelerated aging tests. These tests consist in varying the relative humidity, the temperature and water immersion [10–12]. Results show that variations in functional properties are observed, such as an increase of thermal conductivity and water vapor sorption capacity and a decrease of acoustic performance [13], but also a decrease in compressive strength [12]. These aging tests are highly aggressive, as they are based on immerging the samples and/or putting them at a very high or very low temperature. They do not represent the real conditions in continental climate of buildings and one could wonder if it corresponds to a real aging of construction materials.

In this work, a different aging protocol is carried on to characterize the evolution of the hygrothermal properties of bio-based materials. In order to be more representative of the real aging of building materials, the aging tests will be based on partial immersion and drying at a relatively low temperature. Different samples of hemp lime concrete will be tested and their properties will be determined before and after the laboratory aging. The thermal conductivity, the capillary absorption coefficient and the moisture buffer capacity will be determined.

## 2 Materials and Methods

### 2.1 Materials

The material of interest in this work is hemp lime concrete. Hemp lime concrete is constituted of hemp shives, a lime-based binder and water. The mix proportions are presented in Table 1 and the water/binder ratio was adapted to the shives, with consideration of their water absorption coefficient. The used mixer is of type Eirich and the mixing lasts approximately 10 min.

**Table 1.** Mix proportions of hemp lime concrete

| Material | Shives | Binder | Water |
|---|---|---|---|
| Hemp concrete | 7 kg | 35 kg | 28 kg |

The used hemp shives are provided by BIOFIB (from France) and they result from the defibration of hemp fibers, with no use of water or solvent. Their hygrothermal and physical properties were determined following the RILEM recommendations [14]. Their measured thermal conductivity is 64 ± 7 mW/m.K and their measured density is 107 ± 4 kg/m$^3$.

The water absorption of hemp shives was also determined following RILEM recommendations [14] and the results are presented in Fig. 1. The evolution of water content as a logarithmic function of time as proposed in literature [15] and two specific parameters were determined using Eq. (1).

$$W = IRA + K_1 \times ln(t) \tag{1}$$

W is the water absorption, IRA is the initial rate of absorption and $K_1$ is a parameter indicating the diffusion rate of water that is linked to the intrinsic porosity.

The obtained IRA after one minute is 231% and the parameter $K_1$ is 18 and these values are consistent with literature for other bio-aggregates, including different types of hemp shives [16]. The logarithmic evolution of the water absorption as a function of time is in good agreement with literature [15, 16], as it follows a linear evolution with a coefficient of determination R2 = 0,99.

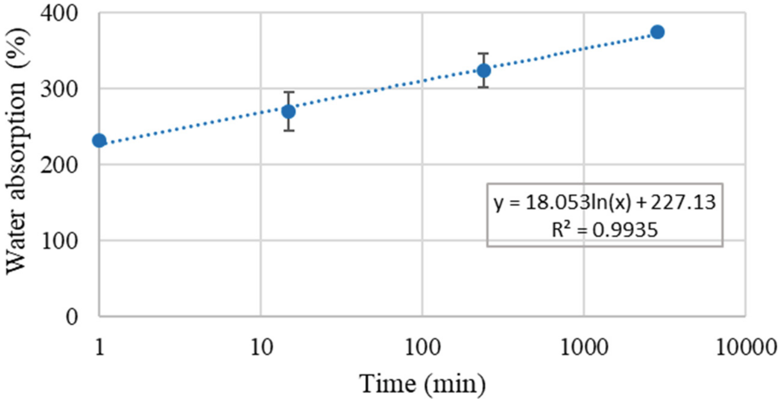


**Fig. 1.** Water absorption of hemp shives

Hemp lime concrete mixes were then put into different molds corresponding to the characterization tests. They were compacted on a vibrating table, to ensure homogenization and to eliminate the trapped air bubbles. After manufacturing, the samples were stored at 21 °C and 30% of relative humidity for 28 days. The reference samples are tested at 28 days and the aged samples are tested after the aging protocol.

### 2.2 Aging Protocol

The accelerated aging protocol is based on successive cycles of immersion and drying. The partial immersion was at room temperature (25 °C) and lasted 2 days, while the water immersion level was maintained at 8 mm (Fig. 2). The sides of the samples were covered to ensure a unidirectional flow, as shown in Fig. 2. The drying was carried on in a ventilated oven for 3 to 5 days at 40 °C. Samples were exposed to 8 cycles of immersion/drying before the determination of their hygrothermal properties.

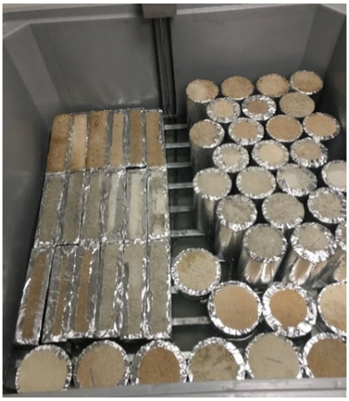

**Fig. 2.** Accelerated aging setup (Partial immersion)

### 2.3 Methods

**Thermal conductivity**. The thermal conductivity was measured using the hot wire method [19] (Fig. 3a). Samples were conditioned at 21 °C and 30% until mass equilibrium before characterizing them. Three 70 × 70 × 280 $mm^3$ parallelepiped samples of each material were tested before and after the aging. The thermal conductivity measurements were carried on at a temperature of 22 °C and a relative humidity of 60%.

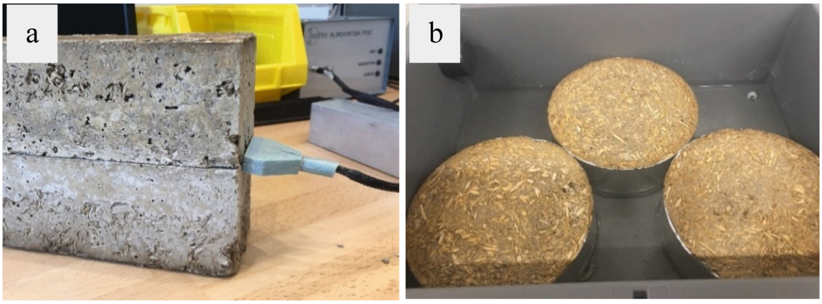


**Fig. 3.** (a) Thermal conductivity measurement; (b) Water absorption setup

**Water absorption coefficient**. The water absorption coefficient was determined following the standard given by AFPC-AFREM [17]. The test was carried on three cylindrical samples of hemp lime concrete and their dimensions were 150 mm of diameter and 50 mm of thickness. Preconditioning was based on drying the materials in a ventilated oven at 80 °C until mass variation is less than 0,1% over 24 h. Samples were covered on their sides to ensure a unidirectional water flow, as can be seen in Fig. 3b. The test was performed in a room controlled in temperature (22 °C) and relative humidity (55%).

The water absorption coefficient is calculated following the Eq. (2) and is expressed in kg/m$^2$.

$$C_a = \frac{M_x - M_0}{A} \tag{2}$$

$M_x$ (kg) is the sample mass at a certain time, $M_0$ (kg) is the initial sample mass and A (m$^2$) is the exposed sample area.

**Moisture Buffer Value**. The moisture buffer value is an indicator of the materials capacity to moderate the variations of indoor humidity in buildings. It was determined following the NORDTEST method [18] that proposed a standardized quantity to characterize the moisture buffering capacity of a material. The test was performed on three cylindrical samples of 110 mm of diameter and 40 mm of thickness, as can be seen in Fig. 4. It consists in submitting the samples to multiple cycles of 8 h of high humidity (75%) followed intermittently by 16 h of low humidity (33%). Temperature is kept constant at 23 °C. Specimens were sealed on all but one surface and weighed or intermittently during the test. The test is over when the weight amplitude do not vary by more than 5% from day to day.

The moisture buffer value is obtained using the Eq. (3) and it is expressed in g/m$^2$.%HR)

$$MBV = \frac{\Delta m}{A * (RH_{High} - RH_{Low})} \tag{3}$$

$\Delta$m (g) is the mass loss/gain during a cycle, A (m$^2$) is the sample exposed area and $RH_{High}$ (resp. $RH_{Low}$) is the high (resp. Low) relative humidity value (%).

**Fig. 4.** Hemp concrete samples in a climatic chamber for MBV measurements

# 3 Results

## 3.1 Thermal Conductivity

Thermal conductivity of hemp lime concrete was measured at the reference state after 28 days of manufacturing and after the accelerated aging. The obtained results are displayed in Fig. 5 and show a decrease of the thermal conductivity after the aging.

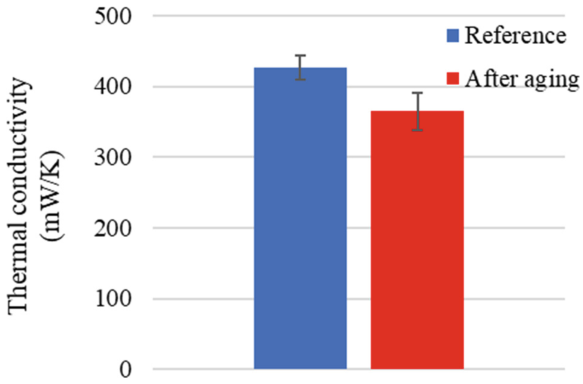


**Fig. 5.** Thermal conductivity of hemp lime concrete before and after aging

Indeed, thermal conductivity of hemp lime concrete at the reference state is 426 mW/m.K and it reaches only 364 mW/m.K after the accelerated aging, which corresponds to a decrease of 15%. This is due to the immersion and drying cycles that alter the microstructure of the material, thus creating more porosity and a lower thermal conductivity. This is consistent with previous works [12]. Their results show a decrease of 6,6% in thermal conductivity and link it to an increase in porosity because of the modification of the microstructure.

## 3.2 Water Absorption Coefficient

Water absorption of hemp lime concrete was determined after 0.5, 1, 2, 4, 8 and 24 h. Samples were tested both at the initial state and after the accelerated aging. Figure 6 presents the evolution of the capillary absorption over time. Results show that water absorption of hemp lime concrete decreases after the laboratory aging and the decrease is higher with time. The water absorption coefficient is defined as the water absorption after 24 h of immersion. It is equal to 4,26 kg/m$^2$ at the reference state and 3.02 kg/m$^2$ after aging, which corresponds to a decrease of 30%. This could be linked to a change in the materials microstructure that would induce less capillary flow.

## 3.3 Moisture Buffer Value

Moisture buffer value of hemp lime concrete was determined before and after the accelerated aging. The mass variation of the different samples during the test is presented in

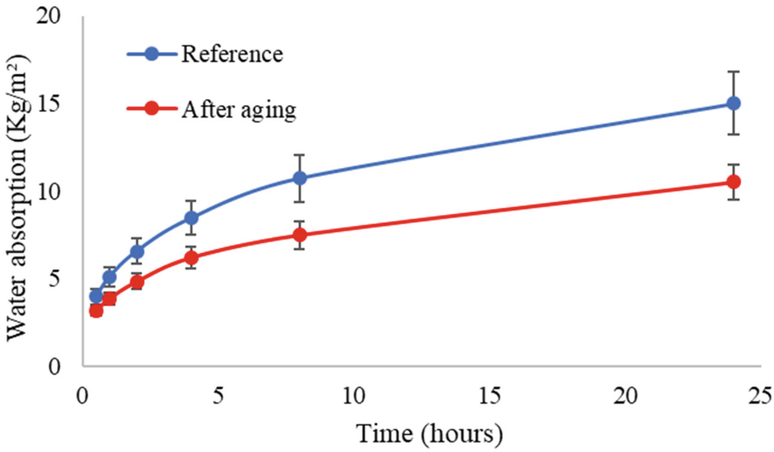


**Fig. 6.** Water absorption of hemp lime concrete before and after aging

Fig. 7, but only the last 5 cycles were presented, from 120 h. Results show that the mass loss/gain is slightly higher for the reference samples.

The moisture buffer capacity of hemp lime concrete is 1,7 g/m$^2$.%RH and is equal to 1,4 g/m$^2$.%RH after aging, which corresponds to a decrease of 16%. The results indicate a good moisture buffer capacity of hemp lime concrete, as it is mentioned in the classification proposed by the NORDTEST project [18], but the results are slightly lower than those found in previous works [7, 12]. The environmental aging decreases the moisture buffer value of the materials and thus alters their moisture regulation capacity. This may be due to the aging of the hemp shives that causes a degradation of their capacity to adsorb and restore moisture.

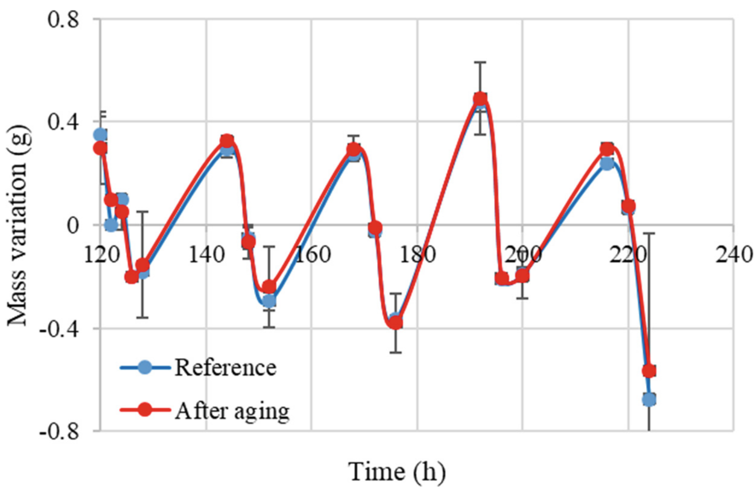


**Fig. 7.** Mass variation for MBV measurements before and after aging

## 4 Conclusion

In this work, durability of hemp lime concrete was investigated through a laboratory accelerated aging. A new aging protocol was followed, in order to get closer to real aging of building materials. The aging protocol was based on partial immersion only and drying at a moderate temperature. Multiple samples were put in 8 mm height of water during 2 days and then dried at 40 °C in a ventilated oven during 3 to 5 days. Their thermal conductivity, water absorption and moisture buffer capacity were determined before and after the accelerated aging, in order to evaluate its influence on materials durability. Results showed that the accelerated aging of hemp lime concrete decreased its thermal conductivity, its water absorption and its moisture buffer capacity.

Further work needs to be carried on, regarding the microscopic variations of the materials structure, but also its mechanical performance. Different compositions of hemp concrete but also flax concrete are going to be tested, in order to assess the influence of the used shives and/or binder on the hygrothermal and mechanical properties of the materials.

## References

1. Osanyintola, O.F., Simonson, C.J.: Moisture buffering capacity of hygroscopic building materials: experimental facilities and energy impact. Energy Build. **38**, 1270–1282 (2006)
2. Peñaloza, D., Erlandsson, M., Falk, A.: Exploring the climate impact effects of increased use of bio-based materials in buildings. Constr. Build. Mater. **125**, 219–226 (2016)
3. Holopainen, R., Tuomaala, P., Hernandez, P., Hakkinen, T., Piira, K., Piippo, J.: Comfort assessment in the context of sustainable buildings. Build. Environ., 60–70 (2013)
4. Amziane, S., Collet, F. (eds.): Bio-aggregates Based Building Materials. RSR, vol. 23. Springer, Dordrecht (2017). https://doi.org/10.1007/978-94-024-1031-0
5. Rahim, M., et al.: Characterization of flax lime and hemp lime concretes: hygric properties and moisture buffer capacity. Energy Build. **88**, 91–99 (2015)
6. Limam, A., Zerizer, A., Quenard, D., Sallee, H., Chenak, A.: Experimental thermal characterization of bio-based materials (Aleppo Pine wood, cork and their composites) for building insulation. Energy Build. **116**, 89–95 (2016)
7. Asli, M., Brachelet, F., Sassine, E., Antczak, E.: Thermal and hygroscopic study of hemp concrete in real ambient conditions. J. Build. Eng., 44 (2021)
8. Palumbo, M., Lacasta, A.M., Holcroft, N., Shea, A., Walker, P.: Determination of hygrothermal parameters of experimental and commercial bio-based insulation materials. Constr. Build. Mater. **124**, 269–275 (2016)
9. Nozahic, V., Amziane, S., Torrent, G., Saïdi, K.D., Baynast, H.: Design of green concrete made of plant-derived aggregates and a pumice–lime binder. Cement Concr. Compos. **34**, 231–241 (2012)
10. Arizzi, A., Viles, H., Martín-Sanchez, I., Cultrone, G.: Predicting the long-term durability of hemp–lime renders in inland and coastal areas using Mediterranean, Tropical and Semi-arid climatic simulations. Sci. Total Environ., 542 (2016)
11. Marceau, S., et al.: Influence of accelerated aging on the properties of hemp concretes. Constr. Build. Mater. **139**, 524–530 (2017)
12. Benmahiddine, F., Bennai, F., Cherif, R., Belarbi, R., Tahakourt, A., Abahri, K.: Experimental investigation on the influence of immersion/ drying cycles on the hygrothermal and mechanical properties of hemp concrete. J. Build. Eng., 32 (2020)

13. Delannoy, G., Marceau, S., Glé, P., Gourlay, E., Guéguen-Minerbe, M., Amziane, S., Farcas, F.: Durability of hemp concretes exposed to accelerated environmental aging. Constr. Build. Mater., 252 (2020)
14. Amziane, S., Collet, F., Lawrence, M., Magniont, C., Picandet, V., Sonebi, M.: Recommendation of the RILEM TC 236-BBM: characterization testing of hemp shiv to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity. Mater. Struct. **50**, 167 (2017)
15. Nozahic, V. : Vers une nouvelle démarche de conception des bétons de végétaux lignocellulosiques basée sur la compréhension et l'amélioration de l'interface liant/végétal. PhD thesis (2012)
16. Bourdot, A., Magniont, C., Lagouin, M., Niyigena, C., Evon, P., Amziane, S.: Impact of bio-aggregates properties on the chemical ineractions with mineral binder, application to vegetal concrete. J. Adv. Concrete Technol., 17 (2019)
17. AFPC-AFREM, Méthodes recommandées pour la mesure des grandeurs associées à la durabilité, Compte rendu des journées techniques AFPC-AFREM (1997)
18. Rode, C., Peuhkuri, R., Time, B., Svennberg, K., Ojanen, T.: Moisture buffer value of building materials. J. ASTM Int. **4**(5) (2007)
19. Alvarado, S., Marin, E., Juarez, A.G., Calderon, A., Ivanov, R.: A hot-wire method based thermal conductivity measurement apparatus for teaching purposes. Europ. J. Phys., 33 (2012)