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Influence of accelerated aging on the properties of hemp concretes

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HIGHLIGHTS

- This paper focuses on the influence of 75 days of wetting and drying cycles on hemp concrete properties.
- Evolutions of the microstructure of hemp concrete can be observed.
- They are not sufficient to induce modifications of the functional properties of the materials.
- Mold growth occurs when the relative humidity is high (98% RH).
- A low value of the pH of the binder is necessary to observe mold growth.

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ABSTRACT

The use of vegetal concretes, such as hemp concrete, is growing for building insulation. They are constituted by vegetal aggregates embedded in a mineral binder. Hemp concretes are multifunctional materials: they have interesting thermal and acoustical performances and their hygrothermal behavior enables a natural moisture regulation. Currently, their use is limited by their lack of guarantees in terms of durability. This paper focuses on the influence of 75 days of wetting and drying cycles on hemp concrete properties. It is shown that this aging induces modifications of the porosity of the materials and of their skeleton density. However, these evolutions of microstructure are not sufficient to lead to modifications of thermal and acoustical performances. This work has also shown that mold growth occurs when the relative humidity is high (98% RH) and when the pH of the binder has decreased due to its carbonation reaction.

1. Introduction

Bio-based materials are increasingly used in the building industry. Partially or totally derived from biomass, their thermal and acoustical insulation properties are likely to improve the energy efficiency and comfort in buildings, whether for new or renovated buildings. However, their poor mechanical properties do not allow them to be used as bearing materials. Therefore, they are used in association with wood or concrete frames.

In particular, materials containing plant aggregates, mainly hemp in France, have been developed and are commonly used for thermal insulation of buildings [1]. Several studies have been published concerning the thermal, hygrothermal, acoustical and mechanical properties of these materials [2–7]. However, their development requires guarantees for users in terms of durability and very few studies exist about this topic [8].

Indeed, these materials constituted from vegetal aggregates (hemp shiv) and mineral binder (based on lime or cement) are highly porous and present interesting hygroscopic properties [9]. Therefore, their properties are likely to change over time depending on their conditions of use (temperature, humidity, ventilation...) [10]. For example, growth of mold or variation of the microstructure can be observed under certain circumstances [11], which will have consequences on the functional properties of the materials.

Few studies focus on the sustainability of hemp concretes [11,12]. The existing ones consist of submitting materials to temperature and relative humidity cycles, and characterizing the evolution of their properties after aging. These works also include the potential fungal growth on the surface of materials. The variations of relative humidity can be significant over short

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periods both inside and outside a building (day/night cycles, rainy season, use by occupants etc.). These cyclic variations might lead to a risk of changes of material performances. In addition, because of their high hydrophilicity, hemp concretes can absorb more than 20% of water by weight when they are submitted to a water-saturated atmosphere [13]. As a consequence, in several works [11,12], hemp concretes were exposed to variations of relative humidity and temperature to reproduce these environments in the laboratory. After aging cycles, few macroscopic changes were observed and it was difficult to differentiate the impact of the different parameters. In other studies focusing on the durability of vegetal fibers reinforced cement composites, the decrease of the mechanical properties after aging is explained by the degradation of vegetal fibers in contact with the cement matrix. Two degradation mechanisms of the fibers have been proposed: their mineralization and the alkaline degradation of the plant cell wall [14,15].

Thanks to the results presented previously, the main parameters that are likely to modify the properties of vegetal concretes are now clearly identified: temperature, relative humidity and mold growth. On this basis, the overall objective of our global project is to investigate the durability of these materials after aging in different exposure environments corresponding to their conditions of use. Therefore, two types of accelerated aging protocols have been developed according to the properties of bio-based materials and to realistic environmental conditions: biological aging (growth of microorganisms in concretes) and environmental aging (cycles of temperature and humidity variations). As a result, this project aims at developing technical recommendations both to optimize the durability of bio-based materials and to quantify their lifetime according to their exposure conditions.

This article presents the first results of the study and focuses on the influence of the type of vegetal aggregates on the properties of the hardened material. The manufacturing of the samples, the conditions of accelerated aging test and the experimental methods used to analyze the materials are presented in the first part. Then, the influence of wetting and drying cycles on the microstructure and on the functional properties is evaluated. Finally, parameters that may potentially affect the mold development on the materials are examined.

2. Materials and methods

2.1. Raw materials

One type of binder has been used in this study: prompt natural cement (PNC). The setting of this binder is very quick and the use of a retarding agent is necessary.

Two hemp shiv from different origins in France, S1 and S2, were tested (Fig. 1):

- Shiv S1 is fibred,
- Shiv S2 is obtained by mechanical defibration of hemp straw. The particles are sieved and without dust.

The main characteristics of these aggregates are reported on Table 1. The values of bulk density and initial water absorption were obtained using protocols set by RILEM TC 236-BBM "Bio-aggregates based building materials" [16].

Bulk density of shiv S1 is clearly lower than shiv S2. This can be partly explained by the presence of fibers, but also by a different particle size distribution and particle bulk density. The initial water absorption of shiv S1 is also lower. It corresponds to the water uptake after one minute of immersion. Finally, shiv S2 has a greater skeleton density, which can be attributed to different culture, climate and production conditions [5].

2.2. Composition of concrete

Two batches of hemp concretes were manufactured according to the procedure defined in the construction rules [17]. Each batch contains one type of shiv and PNC in the same proportions (Table 2). The water to binder ratio W/B was set to 1.5 and the binder to shiv ratio B/S to 2. The compaction of the samples has been adjusted to obtain a density of the fresh concrete of 570 kg.m^{-3}.

Table 1
Characteristics of the hemp shiv.

Hemp shiv	S1	S2
Bulk density (kg.m^{-3})	70 ± 2	95 ± 3
Skeleton density (kg.m^{-3})	750 ± 50	1010 ± 50
Initial water absorption (%)	148 ± 1	168 ± 3

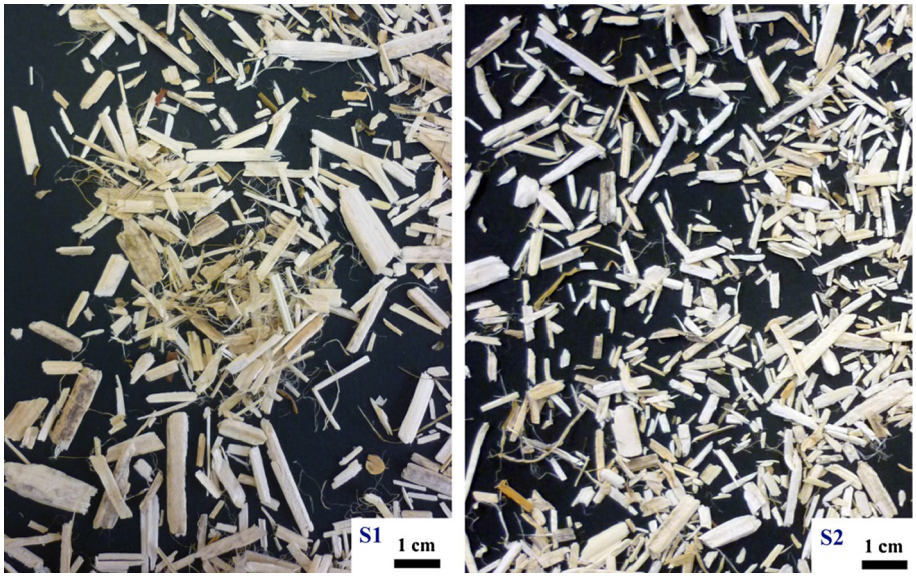

Fig. 1. Two types of hemp shiv in bulk.

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