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Effect of water content on the acoustical and thermal properties of hemp concretes

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HIGHLIGHTS

- For a given shiv, water content of concrete increases with the compaction stress.
- Water content does not affect significantly acoustical properties of hemp concrete.
- An increase in resistivity and a decrease in porosity indicate a swelling effect.
- Thermal conductivity rises almost linearly with water content.

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ABSTRACT

Hemp concrete is a multifunctional ecological material used in buildings. It is obtained by mixing a binder with hemp particles (the non-fibrous fraction of the hemp stem called "shiv" or "hurd"). Due to its high porosity (ranging from 60 to 90%), it presents an "atypical" mechanical behavior and its hygrothermal and acoustical properties are particularly interesting. This paper focuses on the influence of the water content of hemp concretes on their acoustical and thermal properties. Four mixtures of hemp concrete were manufactured using a binder and two shives under two distinct stresses of compaction. It is shown that water content does not affect significantly the acoustical properties of hemp concretes although a swelling effect can be detected by an increase of resistivity and a decrease of porosity. Finally, this study confirms that thermal conductivity rises almost linearly with water content while evolutions of thermal diffusivity and specific heat capacity are different depending on the concrete.

1. Introduction

In developed countries, the global contribution from buildings towards energy consumption has risen sharply in recent decades and has even exceeded the other major sectors in EU and USA: industry and transportation [1]. In France, for example, energy consumption of buildings accounted for 44.8% of overall consumption in 2013 [2]. Reducing this consumption is therefore a major challenge for developed countries. However, the building materials generally used are responsible for significant emissions of greenhouse gases [3,4]: thus, materials with a low environmental impact and excellent thermal insulation properties are now sought after [5–8].

In this context, the solution of bio-based building materials is becoming increasingly relevant as they have very low or even positive impact on the environment (renewable resource, CO_2 storage, reduction of greenhouse gas emissions, etc.) [9–11]. Some of them are also characterized by very good multi-physical properties (heat insulation, sound absorption, transmission loss) [12,13] and are already well established on the building market. Hemp concrete (mixture of wood aggregates from hemp stem with a mineral binder) is among these materials one of the most used in EU.

Hemp concrete is characterized by a highly porous microstructure and has an open porosity ranging from 60 to 90% according to the mixture [14]. Moreover, this porosity is multiscale and distributed as follows:

- Macropores (few mm in diameter) due to the imperfect arrangement of hemp particles in the concrete,

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- Mesopores (from 0.01 mm to 0.1 mm) within hemp shiv and binder,
- Micropores between hydrates (lower than 0.01 μm) in the binder matrix.

Furthermore, the vegetal aggregates are made from different hydrophilic macromolecules. Due to these characteristics, hemp concrete has a highly hygroscopic behavior, which is at the root of particularly interesting hygrothermal performances [15–17]. This also implies a very high sensitivity to water vapor and liquid water, much higher than for conventional building materials [18]. Thus, the mass water content of hemp concrete can reach 10% at relative humidities commonly experienced in a building (50% RH) and exceed 25% in more extreme cases (RH > 90%) [17,19]. However, the impact of the water content of hemp concretes on their thermal and acoustical properties has never been studied systematically. That is why it was decided in this work to study the evolution of acoustical and thermal performance of four different formulations of hemp concrete for various values of water content.

2. Materials and methods

2.1. Raw materials

Hemp concrete specimens were manufactured from one type of binder, Prompt Natural Cement (PNC), marketed by the Vicat group. Due to the quick setting of this binder, the use of a retarding agent was necessary.

Two different hemp shives (called "S1" and "S2") from different origins in France were used (Figures 1 and 2):

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

Due to the presence of fibers in shiv "S1", the analysis of the particles size distribution is not possible by image analysis as it is usually done for vegetal aggregates. Thus, grading curves have been obtained by sieving and describe the values of width and thickness of the particles. They confirmed visual observations that indicate that the dimensions of particles "S1" are higher than for "S2".

The main characteristics of the hemp shives are reported on Table 1. They were obtained using protocols set by RILEM TC 236-BBM "Bio-aggregates based building materials".

Due to the presence of fibers in shiv "S1", its bulk density is lower than for "S2". Its initial rate of water absorption is also lower. It corresponds to the water uptake after one minute of immersion.

2.2. Manufacturing and curing conditions of hemp concrete cylinders

Two batches of 40 L, containing each type of shiv, have been prepared using a concrete-mixer with rotary drum and fixed blades according to a clearly identified procedure [20]. Each constituent was weighed in buckets with an accuracy of 10 g for shiv, water and binder, and 0.1 g for the retarding agent. The following steps were followed for each batch:

- Mixing of the shiv (5 kg) during 1 min in order to separate hemp particles agglomerates,
- Addition of 1/3 of the total water amount (4.33 kg) and mixing during 2.5 min,
- Addition of the retarding agent (30 g) and mixing during 30 s,
- Addition of PNC (10 kg) and mixing during 30 s,
- Addition of the residual water (8.66 kg) and mixing during 2.5 min.

For each batch of hemp concrete, two different stresses of compaction were used: consequently, four sets of "Wall" mixture cylinders were made (see Table 2). The two stresses of compaction were slightly lower (approximately 0.03 MPa) and slightly higher (about 0.06 MPa) than that generally used for this kind of material (0.05 MPa) [20].

For each set, two kinds of specimens were prepared: cylinders measuring 100 mm in diameter and 40 mm in height for measuring the acoustical and thermal properties and cylinders measuring 35 mm in diameter and 40 mm in height for determining the open porosity of hemp concretes. The various characterizations have been repeated on four different samples in each configuration in order to check the reproducibility of the experiment and the deviation between samples.

After their manufacture, the cylindrical specimens were preserved according to a curing protocol which consists of three successive stages:

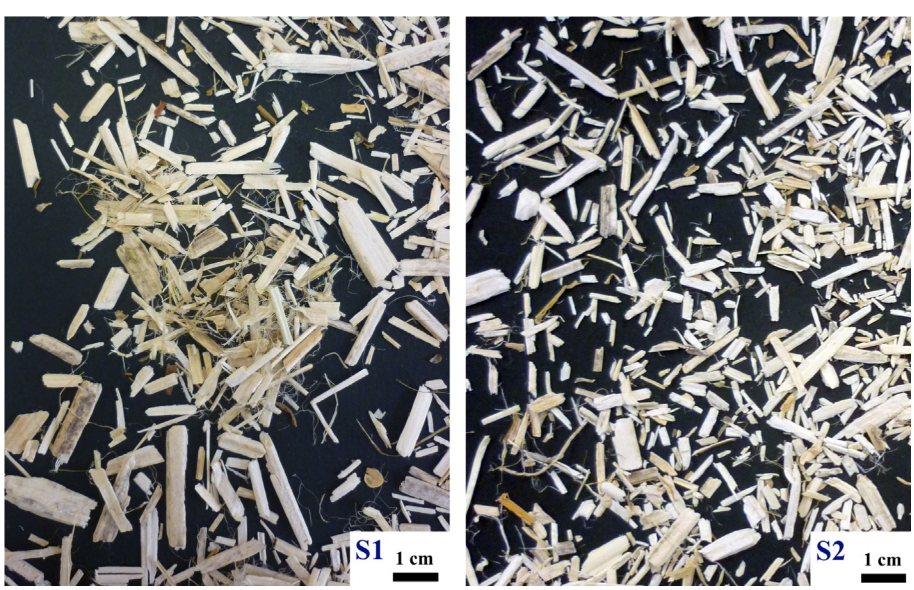

Figure 1. Two types of hemp shiv in bulk.