First International Conference on
Bio-based Building Materials

June 22nd - 24th 2015
Clermont-Ferrand, France

WATER TRANSFERS IN HEMP CONCRETE FOLLOWED BY NUCLEAR MAGNETIC RESONANCE

Marine Fourmentin[1,2] *, Paméla Faure[1], Ulrike Peter[2], Didier Lesueur[2], Philippe Coussot[1]

[1] Université Paris-Est, Laboratoire Navier (ENPC-IFSTTAR-CNRS), Champs-sur-Marne, France
[2] Lhoist Recherche et Développement, Nivelles, Belgium

*Corresponding author; e-mail: marine.fourmentin@ifsttar.fr

Abstract

Hemp is used as an aggregate in hemp concrete, which is mainly constituted of hemp, cement, lime and water. As hemp is known to have a good affinity to water, it is important to understand its water uptake capacities. NMR relaxometry measurement allowed us to follow the kinetics of imbibition of water in hemp. Our results show that imbibition develops progressively over three days, which is far more than we can expect for porous media, even with nanopores. Then, water transfers between the different phases of hemp concrete were followed by NMR measurements. Due to the very different values of the NMR relaxation times of water in hemp and in the binder, we were able to observe the transfer of water from hemp to binder during the first week of setting.

Keywords:

Hemp, Hemp Concrete, Hydric Transfers, Porous Media, NMR

1 INTRODUCTION

Hemp concrete is a mixture of hemp shives and binder, which consists of a mix of cement and hydrated lime. This material is appreciated for properties as a lightweight material and as thermal insulator and moisture regulator. In fact, hemp is known for its affinity to water and for its capacity to soak it up very quickly [1].

Although the affinity of hemp to water is known, only few studies focused on the understanding the imbibition of hemp. As water transfers can occur during setting between hemp and binder, it is important to understand the water distribution during the mixing and the water transfers during setting of hemp concrete.

In a first part, we used Nuclear Magnetic Resonance to study the imbibition of hemp. With NMR, we were able to distinguish different types of pores in hemp and quantify the amount of water entering these pores during imbibition. Our results show that imbibition develops progressively over three days, which is far more than we can expect for porous media, even with nanopores. In a second part, we monitored the setting of a hemp concrete, and were able to quantify the amount of water in both hemp and binder and show that in the first week of setting, hemp transfers a significant amount of water to the binder.

2 NMR RELAXOMETRY

NMR is a non-destructive method that allows the detection of protons of water in a liquid state in a porous media by measuring their spin-lattice relaxation time (T_1) [2]. NMR measurements provide two important data. T_1 is assimilated to an average pore size in the sample, and the smaller the T_1 is, the smaller the pores are. T_1 distribution shows the various pore sizes in the sample and allows following pore size evolution. Plus, it provides quantitative measurements giving the amount of non-bounded water in the system. Protons in water that reacted with anhydrous cement grains to form hydrates are no longer detectable.

3 HEMP IMBIBITION

3.1 Sample preparation

In order to understand transfers within hemp concrete, we need to know how hemp acts in the presence of water. Therefore, hemp was placed in an excess of water, meaning a water to hemp ratio higher than 4, during NMR measurements. In order to obtain a maximum signal in the pores of hemp, hemp was compressed in the bottom of the NMR tube. It was then covered with water and the tube was closed in order to avoid any evaporation.

3.2 Results and discussion

The distribution of relaxation times for such a sample brings up two peaks (fig.1). The peak at higher relaxation times (around 2000 ms) has a T_1 close to the one of water in "no pores" or very big pores. This means that this peak corresponds to water that is situated around hemp particles. On the contrary, the peak at lower T_1 (300 ms) corresponds to water that entered the hemps pores.

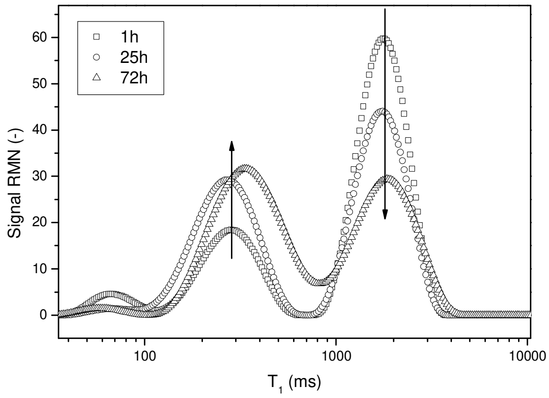

Fig. 1: Distribution of relaxation time of hemp in an excess of water after 1 hour (squares), 24 hours (circles) and 72 hours (triangles) of imbibition. Left peak correspond to signal inside the pores and right peak correspond to water between hemp particles.

If we now look at the evolution of signal after 24 and 72 hours, we see that the signal corresponding to water outside the pores (right peak area) seems to decrease during imbibition while signal corresponding to water in the pores (left peak area) seems to increase. In order to verify this and quantify the evolutions, we represented the amount of signal corresponding to each peak during the entire time of imbibition (fig.2). Half of total amount of signal was also represented on the same figure.

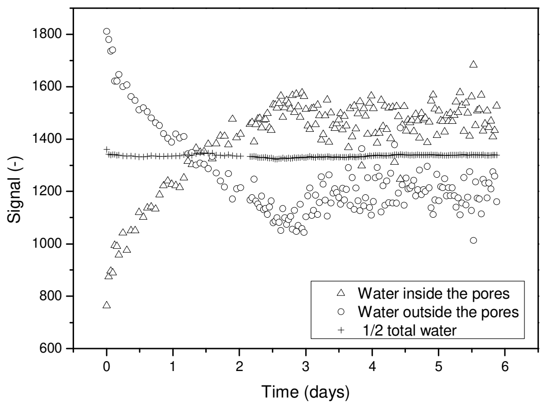

Fig.2: Evolution of the amount of signal in both left (triangles) and right (circles) peak. Half of the total signal is also represented (crosses).

First of all, we can easily verify that the total water amount remains constant during the imbibition, which is what we expect of a sealed tube. Then we can observe that the signal corresponding to water in the pores, which is directly proportional to the amount of water in the pores, increases. Meanwhile, the amount of water outside hemp shives decreases. With this measurement, NMR allows us to clearly see the transfer of water from the outside to the inside of hemp. Plus, we can note that the signal of water in hemp develops progressively over three days, which is far more than we can expect for porous media, even with nanopores.

4 WATER TRANSFERS IN HEMP CONCRETE

4.1 Sample preparation

Hemp concrete samples as we studied are a mix of hemp shives, cement, hydrated lime and water. Cement and hydrated lime are in the same proportion. They are made using the "slurry" method, which means that cement, hydrated lime and water are mixed together and form a slurry, and hemp is added to the mixture. Tubes are closed during the experiments to avoid drying.

4.2 Results and discution

The distribution of relaxation times for hemp concrete shows two peaks (fig.3). This result can be compared to the distribution of relaxation times of both hemp alone, and a lime-cement paste with the same composition than the binder in the concrete. In this manner, we see that each peak that in the concrete corresponds to one of its constituent: the peak at higher relaxation times (300 ms) gives information on the porous structure of hemp and on water contained in it, while the peak at lower T_1 (25 ms) provides information on water and porous structure in the binder. The fact that the two relaxation times are decoupled allows us following precisely the water amount in each constituent, and the transfers between them.

The distributions of relaxation times were measured every 45 minutes during the first week of setting, allowing us to measure the signal amount in each phase (binder or hemp) of the concrete, which is proportional to the amount of water. The results are represented in fig.4 for both of them. The total water amount is constant, as we closed the tube in order to avoid drying of the sample.

We can observe that the amount of water in hemp clearly decreases during the setting, while the amount of water in the binder increases a little. In this case, the total water amount is not constant, which can be explained by the fact that NMR only detects protons of water in a liquid state. As cement is a hydraulic binder, it reacts with water to form hydrates and the protons present in water go from a liquid state to a solid state. Therefore, NMR gives us the amount of water consumed in the hydration reaction.

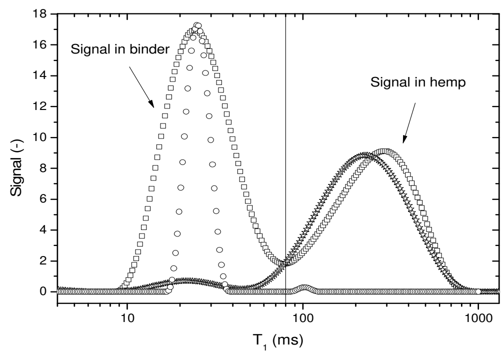

Fig. 3: Distribution of relaxation time of a hemp concrete (squares), a lime-cement paste (circles) and hemp (stars).

Plus, we have information on the initial water distribution at the beginning of the monitoring: the binder contains two thirds of total water, and hemp contains the last third. And in the following hours, the water content in hemp decreases, which means that hemp transfers water to the binder.

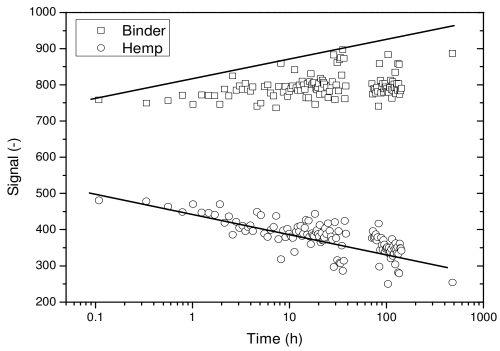

Fig. 4: Evolution of signal in binder (squares) and hemp (circles) during the first week of setting of a hemp concrete. This signal is directly proportional to water amount. The bottom straight represents the evolution of water in hemp and the upper straight is its symmetrical, which represent total water in the binder (in both liquid and solid state)

As we know that the total water amount is constant, if we plot the evolution of signal in hemp, the symmetrical straight for the binder represents the total water amount in the binder, which means both liquid water in the pores of the binder and water that already reacted to form hydrates. Therefore, the difference between the upper straight and the measured signal for the binder corresponds to the loss of signal due to water consumption in cement hydration.

5 CONCLUSIONS

In this study, we used NMR relaxometry to quantify water in hemp during hemp imbibition. We showed that water penetrate in hemp during three days, which is far more that we expect from classical porous media. Due to the very different values of the NMR relaxation times of water in hemp and in the binder, we were able to show the transfer of water from hemp to binder during the first week of setting.

6 REFERENCES

[1] M. Le Troedec, "Influence of Various Chemical Treatments on the Composition and Structure of Hemp Fibres." *Composites Part A: Applied Science and Manufacturing* 39, p. 514–522, March 2008.

[2] P. F. Faure, S. Rodts, « Proton NMR relaxation as a probe for setting cement pastes », *Magn. Reson. Imaging*, vol. 26, n° 8, p. 1183-1196, oct. 2008.