EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF HYBRID HEMP-FLAX COMPOSITE MATERIALS

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Abstract

An experimental investigation was conducted in order to study the water absorption, mechanical performance and drying shrinkage of hybrid hemp-flax composite materials. The hemp-flax composite material is made with 90% hemp shives and 10% flax fibres. Hemp aggregates have a high capacity for water absorption, which led to a reduction of the mechanical performances of hemp concretes. The purpose of this study is to investigate the influence of the incorporation of short flax fibres in hemp concrete. Four mixes were made for: shuttered walls, external rendering, floor insulation and roof insulation. In first stage, the water absorption of flax and hemp shives was measured. The compressive strengths of these mixes were then determined to compare the mechanical behaviour of the hybrid composite material with hemp concrete and the capillary absorption of these bio-based materials were also measured. The endogenous shrinkage of these materials was also measured. Finally, we measured the coefficient of thermal conductivity of these materials. The results of the compressive strength show a significant improvement due to the hemp-binder ratio. The incorporation of the flax fibres in hemp concrete also led to an increase of the compressive strength for large strains (above 5%). It was observed that the capillary absorption of hybrid composite was decreased when a high content of binder was used. Finally, flax fibres have reduced hempcrete shrinkage of about 15%.

Keywords:

Flax fibres, hemp shiv, water absorption, mechanical performances, shrinkage

1 INTRODUCTION

It is estimated that the building sector is currently responsible for 24% of CO_2 emissions and 44% of the energy consumption in France [Ademe 2012]. New building insulation standards tend to decrease the amount of energy used for heating, which accounts for almost two thirds of the energy consumption and the main part of the CO_2 emissions in the building sector in France. However, in this context, energy expenditure devoted to the manufacture and the implementation of construction materials continues to increase. Regarding France's commitments to the Kyoto protocol for 2050, new materials based on agricultural resources are needed.

The sustainable development is a concept that is now present into the collective consciousness. It is no longer a matter of improving housing insulation. Building companies and professionals must now take into account the environmental aspects of the project. This involves the use of materials with low environmental impact [Ademe 2005].

The plants have been largely forgotten by modern technologies. The evolution of the means of production, the need for materials compatible with sustainable construction, consumer expectations and regulatory requirements mean that their qualities are attracting more and more interest. Among the plants usable in the construction, hemp certainly has a privileged position and can be considered as a model. Hemp is distinguished by its environmental assets such as its contribution to the improvement of the soil, its neutral carbon accounting, its low embodied energy expenditure and its end of life without consequences for the environment [Boutin 2005].

From hemp is extracted shiv, which is mostly used as litter for animals thanks to its absorbent properties. [Bouloc 2006]. But the shives may have a different destiny. Mixed with binders (lime and/or cement prompt) and water, it can be used to make a hemp concrete.

This new material is used only for twenty years in construction in France. For ten years, many research has been conducted on this material, which now allows to better understand its mechanical and hygrothermal behaviour. Nevertheless, its use remains marginal (0.15% of material consumption in France) [Ademe 2007]. This is due to a misunderstanding of this product by the general public and mistrust on the part of building professionals. These concerns regarding this material could be corrected if it was proven that the hemp concrete is a material as efficient and durable as its competitors on the marketplace.

The very low bulk density of hemp shives, related to the alveolar structure of the stem from which it originated, gives to hemp concrete a significant lightness and a low thermal conductivity. However, this structure also resulted in low strength and low rigidity of the material after curing [Cérézo 2005, Eires, 2006, Chamoin 2013, Nguyen 2010].

Currently, hemp concrete is most frequently used in lining or filling to form a construction element having good thermal and sound insulation without structural contribution. Most published research is focused on its thermal and hygrometric properties which result from the highly porous structure of the hemp shives [Collet 2004, Evrard 2008, Tran Le 2010, Aït Ouméziane 2013]. However, its mechanical properties have also been the subject of several studies [Cérézo 2005, Elfordy 2008, Magniont 2010, Nguyen 2009, Arnaud 2012, Nozahic 2012, Walker 2010]. Generally, hemp concrete compressive strength remained relatively low compared to other conventional building materials, often less than 2 MPa.

Hemp concrete was often directly implemented on the construction site, or manually into forms or by projection [Elfordy 2008]. These methods of implementation does not allow to reach a sufficiently high compactness. Nevertheless, it is quite feasible to apply a process by significantly compacting the material and precisely control its formulation and its short-term maturity. The current state of knowledge does not give recommendations regarding the shives characteristics for use in hemp concrete or established method for its preparation. Furthermore, the exchange of water between the shives and the binder matrix are difficult to predict during the implementation. The increase in rigidity by the binder does not result in a significant increase in the overall mechanical strength [Eires 2005]. However, the compaction led to better results and confirms that a better compactness led to an increase in the mechanical performances of the hemp concrete [Cérézo 2005, Nguyen 2009].

Hemp aggregates have a particle size predominantly between 1 and 5 mm [Cérézo 2005]. Flax fibers have diameters around 5 to 80 microns [Roudier, 2013]. Flax fibres can therefore be inserted between hemp aggregates and thus increase the compactness of the composite. In addition, the flax fibres can help to improve the behaviour of the hemp concrete in large strains and thereby increase its ductility [Le Hoang 2013].

In France, professional execution rules were published in 2007 for hemp concrete [Construire en Chanvre 2007]. These rules provide four standard hemp concrete formulations for four different uses: shuttered walls, external rendering, floor insulation and roof insulation.

In this work, four formulations were made to study the effect of the binder or hemp contents on the physical and mechanical properties. In first stage, the water absorption of flax and hemp shives was measured. The compressive strengths of these mixes were then determined to compare the mechanical behaviour of the hybrid composite material with hemp concrete and the capillary absorption of these bio-based materials were also measured. The endogenous shrinkage of these materials was also measured. Finally, the coefficients of thermal conductivity of these materials were determined.

2 MATERIALS AND METHODS

2.1 Raw materials

Natural particles

Two different crop by-products were used for this work:

- Hemp shiv used in the experimental program was Tradical® HF. It is a hemp aggregate made from the inner woody core of the hemp plant's stem. Hemp is chopped, graded and de-dusted to give a natural, sound and breathable product. This type of shiv is compatible with lime-based binders and is marketed for individual housing construction in hemp concrete.
- Flax fibers used for this work have a length of 12.7 mm. Monofilament flax fibers are used to improve cohesion, holding, mould-ability, and to limit the cracking of cementitious composites.

Mineral binder

The binder used in this study was Tradical® PF70. It has already used in several other researches for making hemp concrete [Boutin 2005, Evrard 2008, Nguyen 2010, Chamoin 2013]. Tradical® PF70 is a special lime binder based on aerial lime (75%), hydraulic binder (15%) and pozzolanic binder (10%).

This binder has been chosen for its great capacity to generate carbonation reactions. Indeed, aerial lime contains a large amount of calcium hydroxide $Ca(OH)_2$ [Nozahic 2012]. Once mixed with water and aggregates and in the presence of carbon dioxide, carbonation of the lime takes place, converting calcium hydroxide into calcium carbonate ($CaCO_3$). This is a very slow reaction. It starts mainly when lime has sufficiently dried and can last for months or even years.

Then, the hydraulic binder (15 % of the binder) allows a higher reactivity and better short term resistance. Indeed, dicalcium and tricalcium silicates present in the binder will react with water to form calcium silicate hydrates (C–S–H) and portlandite.

Finally, the pozzolanic binder (10% of the composition) will react with calcium hydroxide $Ca(OH)_2$ during the cement hydration and will promote the formation of calcium silicate hydrates [Nozahic 2012].

2.2 Methodology

Mix design

According to the French professional rules for hemp concrete structures [Construire en Chanvre 2007], four different mixtures were used throughout this work:

- Mix A: External rendering.
- Mix B: Shuttered walls.
- Mix C: Floor insulation.
- Mix D: Roof insulation.

Amziane and Arnaud provide dosages based on experience for these four applications [Amziane 2013]. Mix proportions and notations used are presented in Tab. 1.

Two different hemp concretes have been formulated for this study. The first is a conventional hemp concrete, wherein all the introduced aggregates are hemp shives. This concrete will be noted later HC for Hemp Concrete. In the second hemp concrete, 90 % (in mass) of the aggregates are hemp shives and the remaining 10 % are flax fibres. Hemp shives are therefore substituted partially (10% in mass) by flax fibres. This second concrete will be abbreviated FHC for Flax-Hemp Concrete.

Tab. 1: Compositions in dry mass of each mixes for a batch of 1000 g

	Mix A	Mix B	Mix C	Mix D
Aggregate (A)	170 g	230 g	220 g	320 g
Binder (B)	360 g	310 g	410 g	220 g
Water (W)	470 g	460 g	370 g	460 g
A/W mass ratio	***0.36***	***0.50***	***0.59***	***0.70***
A/B mass ratio	***0.47***	***0.74***	***0.54***	***1.45***

Mixing procedure

One of the main difficulties encountered during the hemp concrete mixing is due to the water absorption of plant aggregates. This water absorption creates a problem for the binder which needs to be hydrated [Nguyen 2010]. For this reason, it is essential to take into account the water absorption capacity of the raw natural particles. Thus, hemp shives and flax fibres were first prewetted in the mixing drum during 2 minutes with 65% of the water quantity. Then, the binder was added and mixed during 1 minute. Finally the remaining water (35%) was introduced in the mixing drum and mixed during 2 minutes. The total mixing time was equal to 5 minutes.

Casting procedure and curing conditions

The concrete was poured in the different moulds (50 x 50 x 50 mm² or 100 x 100 x 100 mm²) and compacted in three layers by using a steel manual device (Fig. 1). The height of a single layer is equal to one-third of the total height of the concrete specimen (50 or 100 mm). The first and second layers have been scratched to obtain a good grip surface for the next layer.

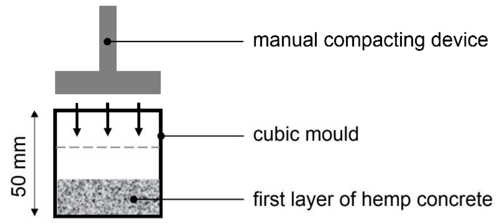

Fig. 1: Compaction process.

Specimens were demoulded after 24 h and stored in a climate-controlled room at 20°C and 60%RH. The shrinkage was measured on prism of 50 x 50 x 200 mm^3. A shrinkage measurement device has been used, so it was necessary to place a metallic ball on both ends of each specimen. To place these balls, a hole was dug at each end of the specimens after release. Then, a quick-setting mortar has been made and applied in holes. Finally, ball was placed in the hole and was semi-embedded in mortar (Fig. 2). The fixation of the ball is a crucial step for the shrinkage measurement. After balls fixation specimens were packed in silver foil in order to stay in endogenous conditions with no air exchange.

Fig. 2: Prisms manufacturing.

2.3 Experimental procedures

Water sensitivity of natural particles

The working group RILEM TC 236 has developed an experimental protocol for measuring the water absorption of bio-aggregates. The protocol is as follows:

4. Dry 200 grams of aggregates at 60°C up to ± 0.1% mass variation in 24 hours is achieved.
5. Put a synthetic or metallic bag (with holes around 1 mm²) in water for a complete wetting.
6. Put the bag in a salad spinner and turn it 100 times at approximately 2 rotation per second.
7. Tare the spinned bag and note the value.
8. Weight 25 grams (M_0) of dry aggregate and put it in the water permeable bag.
9. Put the bag of aggregates in water for 1 minute.
10. Put this bag in a salad spinner and turn it 100 times at approximately 2 rotation per second.
11. Weight the spinned aggregates bag and note the M_1 value (1 min).
12. Repeats steps 6, 7 and 8 with the sample at different times: 15, 240 and 2880 minutes.
13. Calculate the value of absorption with this formula:

$$M(t) = \frac{M(t) - M_0}{M_0} * 100 \quad (1)$$

This test was conducted on hemp shives and flax fibres. In order to see the repeatability, this test was carried out 3 times for each aggregates.

Compressive strength testing

The compressive strength was determined by crushing three cubes of 50 mm size, by using an electromechanical testing machine (Zwick). Displacement control tests were conducted with a loading rate of 3 mm/min.

Capillary water absorption test

Capillary water absorption was measured at 7 d by using a cube of 100 mm size. Specimens have been preserved in a controlled room.

The purpose of this test is to simulate a capillary rising in a wall. This method is based on EN 13057 standard relating to the determination of capillary absorption of concrete structures. A waterproof tape was applied around the circumference of the test piece. Test pieces were then placed in a plastic container on two steel bars (to ensure water absorption only on the underside of the specimen). Finally, the container was filled with water until obtain an imbibition front of 8 mm. Water level was maintained to 8 mm during the time of the experiment (Fig. 3).

The specimens were weighed at specified time intervals until 48 h. The mass of water absorbed by surface unity (kg m^{-2}) is defined as follows:

$$M_w = \frac{M - M_0}{A} \quad (2)$$

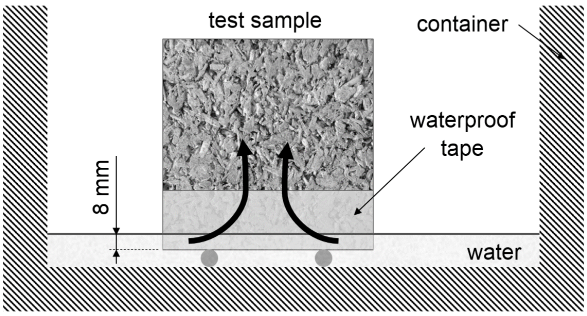

Fig. 3: Measuring method of capillary water absorption.

Shrinkage measurement

Two samples of each mix were tested using French cement standard NF P15-433 (1994). Measurements were made using a shrinkage apparatus having an accuracy of 0.001 mm and performed every 2-4 days up to 46 days.

Thermal conductivity

Thermal conductivity of HC and FHC specimens was measured with a thermal apparatus (conductivimeter) using the transient hot-wire method (EN ISO 8894). This method consists in generating a heat flow by Joule effect and measuring the temperature variation over time by means of a thermocouple. This thermocouple is associated with the heating element in the hot-wire probe. The rise in temperature measured by the sensor is limited to 20°C and the measuring time is dependent on the material, here taken as 60 seconds. The temperature variation (ΔT) is related to the electrical power (P), the wire length (L) and the thermal conductivity (λ) [Franco 2007]. If the temperature is measured at times t1 and t2, the thermal conductivity is given by Eq. (3) :

$$\lambda = \frac{P}{4.\pi.L.\Delta T} * \ln\left(\frac{t_2}{t_1}\right) \quad (3)$$

Measurements were done by positioning the thermal probe between two specimens of same mix (Fig. 4) and have been tested three times.

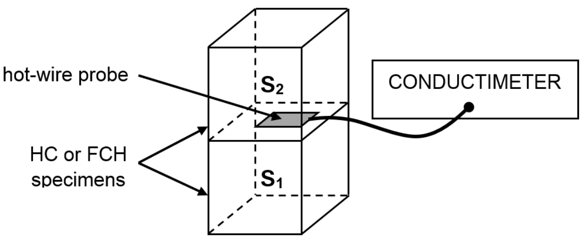

Fig. 4: Thermal conductivity measurement with the hot-wire probe.

3 RESULTS AND DISCUSSION

3.1 Water absorption of bio-aggregates

The immersion in water curve obtained for hemp shiv has a similar shape to previous tests performed by others [Cérézo 2005, Nguyen 2009, Nozahic 2012].

One can observe two phases of absorption. The first one is a surface absorption phase which causes an almost instantaneous increase of the aggregates mass. It highlights the rapid nature of the wetting of hemp and flax particles. The second phase is the slow absorption into the vegetable structure. This demonstrates the diffusive behaviour of the water propagation in the structure up to 48 hours.

The wetting phase may be considered completed after 1 minute. The initial absorption W_0 was set for this duration. On this value, an important difference is visible between hemp (W_0 = 181%) and flax (W_0 = 84%).

It is visible in Fig. 5 that the intra-granular water absorption follows a logarithmic law. Nozahic has defined the following relationship is valid until saturation aggregates [Nozahic 2012]:

$$W(t) = C_A * \log(t) + W_0 \quad (4)$$

- W_0 : Initial water absorption by the particles;
- C_A : Water absorption coefficient of particles.

It can be observed that the absorption coefficient of hemp shive was almost twice compared to that obtained on flax fibre (C_A = 14.7 vs. 7.5).

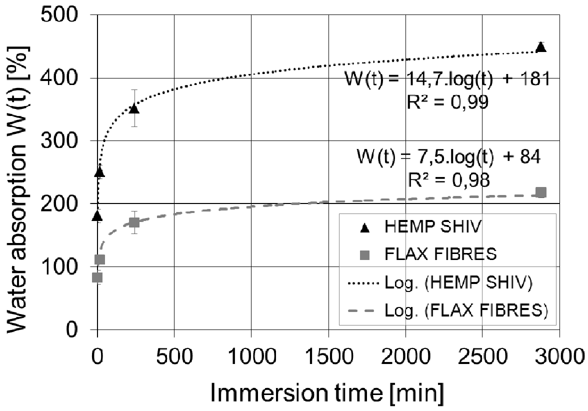

Fig. 5: Water absorption curves of hemp shives and flax fibres.

3.2 Densities of bio-based concretes

The bulk density of hemp concrete was lower compared to the conventional concrete. It ranges from 250 to 500 kg/m^{-3} depending on the formulation [Cérézo 2005]. This is mainly the low density that allows hemp concrete to have good thermal performances. However, density and resistance are also two closely related parameters. Thus, the low resistance of hemp concrete is due to that low density.

Flax fibres have very small diameters compared to hemp shives. The incorporation of flax fibers in has therefore allowed to increase the compactness of the mixture. Fig. 6 presents the bulk densities obtained at 28 days for HC and FHC.

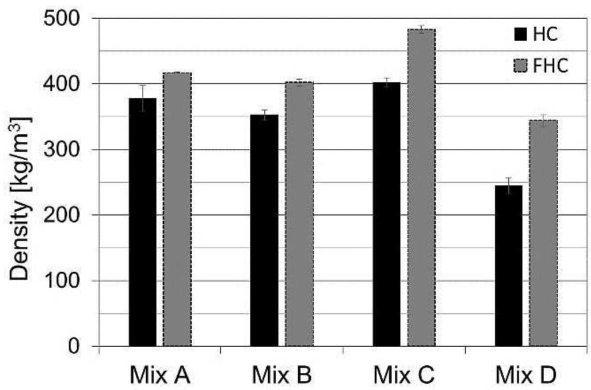

Fig. 6: Densities at 28 days of curing for HC and FHC.

It can be seen in Fig. 6 that replacing 10 % hemp shives with 10% flax fibres affected significantly the increase of the density. Indeed, the density increased from 10.3 to 40.4% according to the formulation.

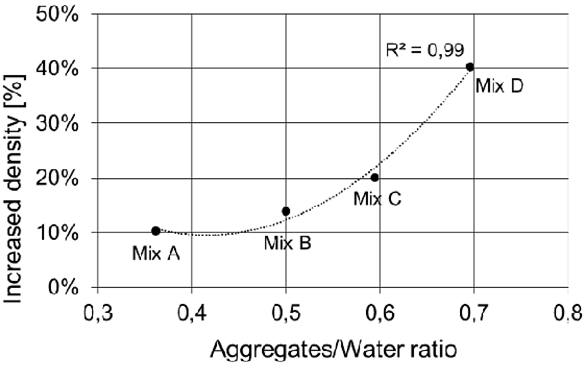

Fig. 7: Increased density between HC and FHC concretes depending on the A/W ratio.

In Fig. 7, it can be observed the density increased between HC and FHC concretes with the increase of A/W mass ratio. The density of hybrid hemp-flax concretes increased with A/W ratio and the trend follows a quadratic polynomial function. The coefficient the coefficient of determination was very close to 1.

In fact, the more the amount of hemp shives increases, the higher intergranular space is. Flax fibres, which have diameters smaller than hemp shiv, was able to be placed into these spaces, thereby led to an increase in the compactness, hence a higher density for hybrid cementitious composites had obtained.

3.3 Compressive strength test

Hemp concrete behaved differently depending on the direction of compaction of the mix [Nozahic 2012]. Conventionally, hemp concretes compacted manually are solicited alongside their compaction direction. The compressive force is thus directed perpendicular to the fibre orientation due to the implementation. Conversely, when the compression test is performed perpendicularly to the direction of compaction, hemp shiv particles (oriented compaction) are more stressed in their longitudinal direction. This is their direction of greater rigidity. The Compressive tests were carried out on cubes of 50 mm size at 28 days.

Perpendicular orientation

Only mix A was tested in compression with a direction perpendicular to the compacting direction. Indeed, mix A is a mixture for an external rendering. For this mixture, hemp concrete is implemented by projection. For this implementation process, hemp concrete is compacted perpendicularly to the loading direction. For mixtures B and C (respectively shuttered walls and floor) the loading direction is parallel to compaction. Finally, for the mix D which corresponds to roof insulation, the orientation is neither parallel nor perpendicular; it depends on the slope of the roof.

The curve obtained for the mix A with a parallel orientation was also plotted (Fig. 8). We first noticed a ductile behaviour for this material. There is no brittle fracture; the material has a large deformation capacity. A compression in the direction orthogonal to the compaction generates a greater elastic modulus and a higher compressive strength than compression carried out in parallel to compaction (Fig. 8). In other words, compression performed in parallel to the preferential orientation plane (longitudinal) of parallelepiped aggregates generates a higher stiffness than when stress is applied on these same particles perpendicularly to this plane. This observation may be related to the wood behaviour, for which is commonly observed mechanical properties more than 10 times in the longitudinal direction of the rod.

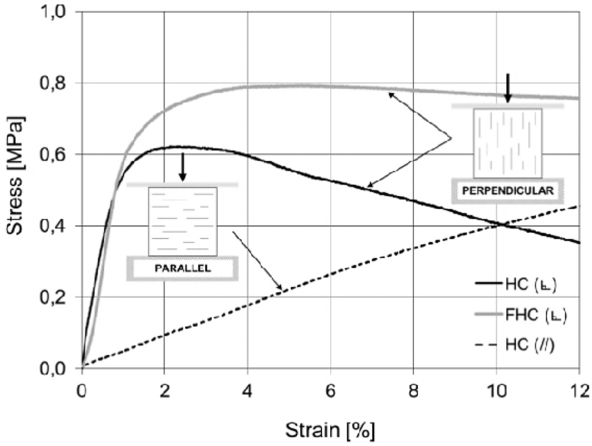

Fig. 8: Mechanical behaviour for HC and FHC with a perpendicular orientation.

In perpendicular orientation, HC hemp concrete has initially an almost linear behaviour up to the maximum stress of about 0.63 MPa. Then, the material continues to be deformed but the stress decreases. For hemp concrete with 10% flax fibres (FHC), the same behaviour is observed. However, the maximum stress is 0.79 MPa, 25% higher than HC. In addition, a different mechanical behaviour is observed for FHC in large strains (above 4% strain). Indeed, the stress remains high while continuing to be deformed. Indeed, the stress remains high while continuing to deform. For FCH, the stress is equal to 0.76 MPa at 12% strain, while it is 0.36 MPa for HC. Thus, flax fibres allow creating reinforcement in the composite material. They limit the cracks opening and slow the concrete failure.

Parallel orientation

The compression test was carried out on all the mixtures for samples stressed in parallel to the compacting direction. As it can be seen in Fig. 9, hemp concrete has a quasi-linear behaviour for a compression in parallel to the compacting direction. There is no maximum stress value, the resistance continues to increase until the end of the test, at 12% deformation. In order to compare the results between them, we defined the resistance at 5% strain as the acceptable maximum stress.

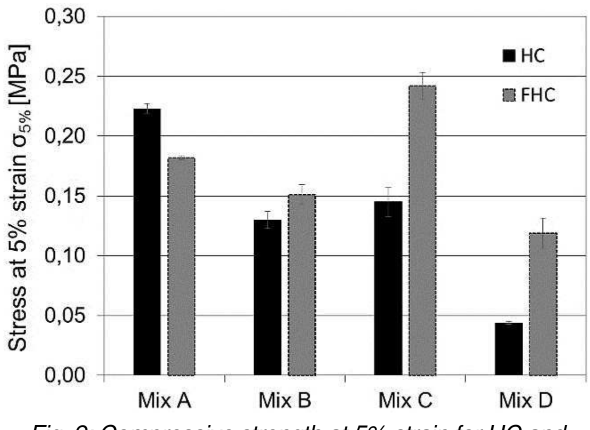

Fig. 9: Compressive strength at 5% strain for HC and FCH with a parallel orientation.

From Fig. 9, it can be seen that the incorporation of flax fibres into the concrete is good for mix B, C and D, respectively with an increase in resistance of 16%, 67% and 170%. Only mix A, which has the lowest amount of hemp has better resistance with HC concrete; a decrease in strength of about 18% for the hybrid-flax hemp composite is observed.

As it can be seen in Fig. 10, there is a relationship between the effect of flax fibres on hemp concrete strength (increase or decrease) and the aggregates/water ratio. Thus, the greater the amount of hemp into the material is, the more flax fibres contribute to improve hempcrete compressive strength.

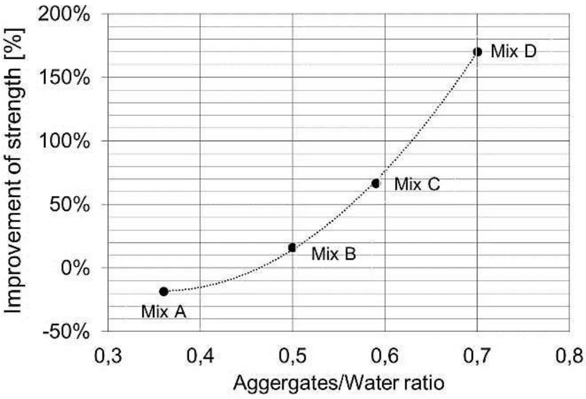

Fig. 10: Increased strength due to flax fibres as a function of the Aggregates/Water ratio.

3.4 Capillary absorption

The capillary absorption is used as an indicator of the degradation of building materials. Moreover, the capillary transport is one of the main driving mechanism for the chloride and sulphate ions so absorbed water can be a problem for durability [Arandigoyen 2006].

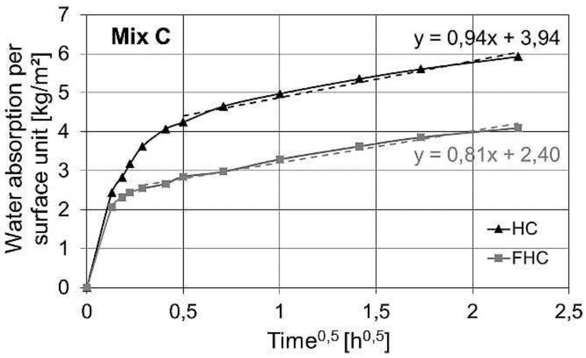

Fig. 11: Capillary water absorption curves for external rendering mixture specimens (Mix C).

The capillary absorption can be described by the water absorption coefficient. The latter results from the gradient of the straight line of curves presented in Fig. 11 as the mass of water absorbed versus square root of time. This capillary water absorption coefficient is defined as C_A (kg.m^{-2}.h$^{-1/2}$) by the following equation:

$$M_w = C_A * \sqrt{t} + k \qquad (5)$$

- k is a function of the contact area with water (kg.m^{-2}) corresponding to the y-intercept of the straight line ;
- $\sqrt{t}$ is the square root of time.

The addition of 10% flax fibres seems to decrease capillary absorption of hemp concrete for mixtures containing a low proportion of vegetable aggregates. Indeed, the C_A coefficient is lower for mixes A and C (Fig. 12). In contrast, the absorption coefficient increased for mixtures containing a higher proportion of hemp, i.e. mixtures B and D.

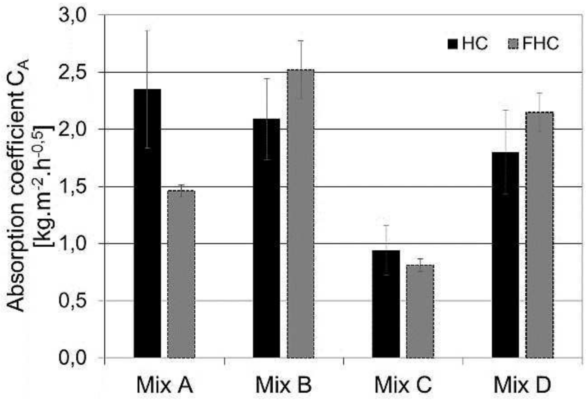

Fig. 12: Absorption coefficients for HC and FHC.

Capillary porosity is defined as residual spaces occupied by the original kneading water. Indeed, some studies show that the capillary coefficient in cementitious materials depends upon the water on binder mass ratio [Arandigoyen 2006]. These same results are obtained with the HC hemp concrete (Fig. 13). The more the Water/Binder ratio is, the more the capillary absorption increases. In fact, the W/B ratio is known to affect the relative volume of solids and capillary voids. The volume of capillary voids increases with the W/B mass ratio and the capillary water absorption is strongly linked to capillary voids.

However, the relationship between the W/B ratio and capillary absorption cannot be seen with FHC hybrid concrete. This could be due to an increase of tortuosity of the concrete pore structure due to the presence of flax fibres, which would complicate the capillary suction phenomenon (Fig. 13).

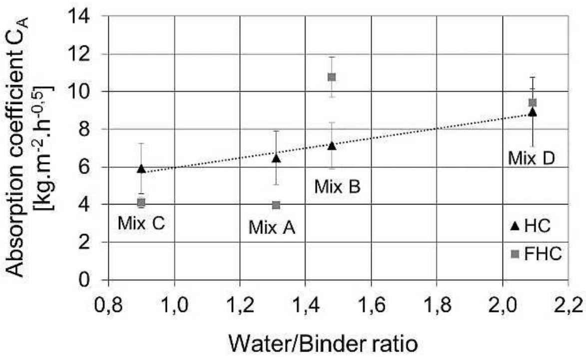

Fig. 13: Relation between the water absorption coefficient and the Water/Binder ratio.

3.5 Endogenous shrinkage

The phenomenon has not been widely investigated for lime and hemp shiv concretes. Murphy nevertheless studied the plastic shrinkage hemp concrete [Murphy 2010]. This study looked at the endogenous shrinkage of that material. Endogenous shrinkage is caused by the cement hydration reaction. This means that the reaction products have lower specific volume than the specific volumes of the reagents. When cement setting is not yet complete, the shrinkage can be done freely. After cement hardening, the phenomenon continues thanks to the capillary tension in the microstructure, with a lower intensity [Barcelo 2005]. The solid skeleton created is opposed to this volume variation, causing shrinkage of the material. After four weeks, more than 2/3 of the endogenous shrinkage has happened.

This same behaviour is obtained with hemp concrete, reinforced or not. The linear increase of the shrinkage was relatively constant up to 25 days. Then the endogenous shrinkage continued to increase slowly until the end of the test to 46 days (Fig. 14). The endogenous shrinkage stabilised for HC concrete, at 8.5 mm/m for mix A and about 4.5 mm/m for mix B. For both A and B mixes, hybrid hemp-flax concrete has a lower endogenous shrinkage of about 15% (7.5 mm/m for mix A and 4 mm/m for mix B). It also appears that the amount of binder introduced into the concrete composition has an effect on shrinkage. Indeed, mix A, which contains more binder, has a higher endogenous shrinkage (+ 90%) than mix B.

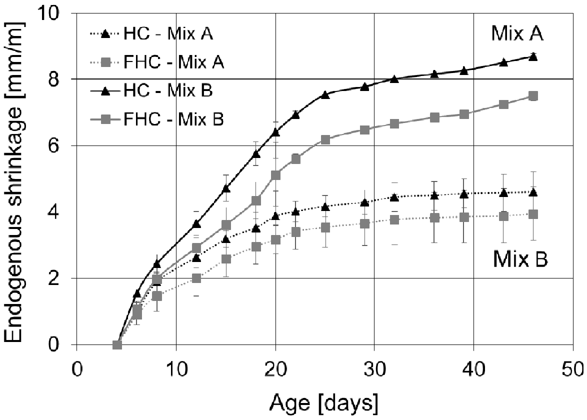

Fig. 14: Endogenous shrinkage for HC and FHC.

3.6 Thermal conductivity

The thermal conductivity of HC and FHC concretes was measured in dry state (drying at 60°C in an oven for 48 hours). Fig. 15 presents the variation of thermal conductivity in function of density. The results show a linear relation between thermal conductivity and hempcrete density. This relationship has already been highlighted by several authors who have been interested in the thermal characteristics of hemp concrete [Cérézo 2005].

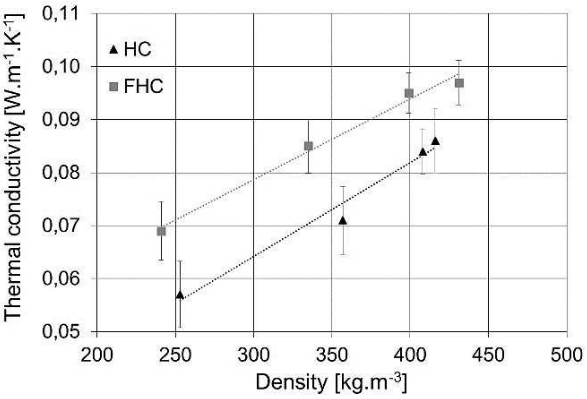

Fig. 15: Thermal conductivity for HC and FHC vs. density.

For a same density, it seems that FHC mixes shows a higher thermal conductivity (Fig. 15) compared to HC mixes. For HC concrete, the thermal conductivity varied between 0.057 and 0.086 $W.m^{-1}.K^{-1}$. However, the thermal conductivity ranged between 0.069 to 0.097 $W.m^{-1}.K^{-1}$ pour FHC hybrid mix.

Thus, the thermal conductivity of the FHC is 12 to 20% higher than that of HC. The values of the coefficient of thermal conductivity were still very low, however, the FHC mixes can be considered as a building material with a good thermal performance.

4 CONCLUSION

A new eco-friendly composite material for building construction has been developed by using hemp shiv and flax fibres as vegetable aggregates and a lime-based binder. In order to assess the performance of the composite material, various tests were performed on the composite material and on the conventional hemp concrete.

First, the water absorption test carried out on the plant aggregates showed the very high capacity for water absorption of hemp shives, almost 450% after 48 hours. Flax fibres had a water absorption about twice lower than that of hemp shive (215% after 48 hours). It was also shown that the water absorption of hemp shives and flax fibres follow a logarithmic law. The water absorption of plant aggregates is known to be problematic for agro-concretes. The lowest water absorption of flax fibres is thus an advantage to formulate bio-aggregate based concretes.

Then flax fibres have improved the mechanical behaviour of hemp concrete on two different points. Firstly, the incorporation of the flax fibres has increased the ductility of the hemp concrete. Even in large deformations (above 5%), the hybrid hemp-flax concrete retains its almost maximum compressive strength. Secondly, hybrid concrete has reached better compressive strength (at 5% strain) for the formulations intended for shuttered wall, floor insulation and roof insulation. This study also highlighted a relationship between this increase in strength and aggregate/water ratio.

Concerning the capillary water absorption, a general trend due to the incorporation of flax fibres could not be observed. However, the hybrid composite appears to have a lower water absorption than the hemp concrete mixtures containing a lower amount of vegetable particles (external rendering and floor insulation). A linear relationship between the coefficient of absorption and the capillary water/binder ratio was observed for the hemp concrete. This relation cannot however be observed for the hybrid hemp-flax composite. This could be explained by an increased complexity of the concrete porosity, and an increased tortuosity of the capillary networks.

The endogenous shrinkage of these two materials was also measured. Hemp-flax hybrid concretes showed a lower endogenous shrinkage of about 15% compared to conventional hemp concrete.

Finally, the thermal conductivity measured for the hemp-flax composite was higher than that of hemp concrete, from 12 to 20%. However, values obtained for the thermal conductivity coefficient were still very low. Therefore, hydrid composite may also be considered as an insulating construction material.

Thus, the incorporation of 10% flax fibres in hempcrete composition has allowed to make an insulating cementitious composite having improved performances than conventional hemp concrete. Further research is needed to find the optimal replacement of hemp shiv by flax fibres. Furthermore, additional test is needed to be conducted in order to better quantify the porosity of these two materials. Finally, the fibers were usually used in concrete to increase their tensile strength. From the same perspective, the bending tests will recommended to be carried out.

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