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LIGHT EARTH PERFORMANCES FOR THERMAL INSULATION: APPLICATION TO EARTH-HEMP

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Abstract

The present study aims at evaluating the impacts of raw materials variability (earth and hemp) on hemp-earth performances. This work is performed in the framework of the ECO-TERRA R&D project in collaboration with four French research laboratories, short circuit hemp producers and craftsmen specialized in hemp and earth constructions. This article is focused on the thermal conductivity, and mention preliminary results of the mechanical characterizations. The results are compared to lime-hemp materials, one of the most studied bio-based concrete for thermal insulation in R&D programs. The typical volumetric mass of a dry lime-hemp mixture is about 330 to 400 kg/m^3, which corresponds to a thermal conductivity about λ = 0,11 W.m^{-1}.K^{-1} (measured with hot plates, at 20°C and 50% relative humidity).

Keywords:

Light-earth, earth-hemp, raw earth, hemp, thermal conductivity, drying path, simple compression

1 INTRODUCTION

The building sector is nowadays one of the first source of pollution. Taking Paris as an example, building heating is the second principal source of pollution with 20% of NO_x emissions in the region and 25% of primary PM_{10} (Particulate Matter) emissions [International Energy Agency 2016]. Regarding these facts, nowadays eco-buildings efforts lead to housing with lower operating energy consumption but higher embodied energy.

Paying attention to the whole building life cycle, the choice of an efficient insulation system with low embodied energy is a must [Thormark 2006]. In addition, environmental impacts can be reduced further by the use of local materials, by the development of local distribution channel and by the evolvement of building professionals who use traditional or local ways to build (Morel et al. 2001; Floissac et al. 2009).

In this context, there is an interest since the nineties for bio-based materials such as straw, hemp... Lime-Hemp mixes for thermal insulation was focused in numerous scientific studies (Collet 2004; Cerezo 2005; Hung Pham et al. 2012; Colinart, Lelievre, and Glouannec 2015; Tran Le et al. 2010). Preliminary estimations shows that replacing lime based binders by unfired clay could reduce by 20 the embodied energy of the insulation constructive system [Röhlen and Ziegert 2013; Keefe 2005], and lower the carbon impact by a factor 5 [Busbridge 2009].

Earth has a much longer story than commonly studied bio-based materials as it has been used for construction from 10 000 years ago in the Middle East. Earth was always used as a heavy material with density ranging from 1200 to 1800 kg/m^3 depending on the techniques. It is only recently that craftsmen and scientists tried to lower the earth density to improve its thermal insulation. The first experiments were carried out in Germany, using straw (Volhard 2016), but other resources can be used, such as coir rape, hemp…

Earth constructions can require almost no transport if earth from the construction site is used. Also, using earth as a construction material needs no, or few, transformations [Keefe 2005]. Moreover, clayey bonds are reversible [Röhlen and Ziegert 2013] and require low deconstruction energy at end-of-life and can be reused for a new construction.

Raw earth and hemp might be subject of numerous variabilities: earth particle size distribution, clay types and chemical components, hemp particle size distribution, dust ratio, fiber ratio and cultivation details for hemp... The aim of the ECO-TERRA project is to evaluate the impact of the components variability on the performance of light-earth, and in particular of hemp-earth.

This paper report the first results obtained regarding thermal and mechanical characterizations of some earth-hemp mixes, including variabilities such as particle size distribution of shiv, clay content of raw earth and shiv/clay ratio.

2 MATERIALS AND METHODS

2.1 Formulations

The studied material is only composed of raw earth and hemp shiv. Raw earth was obtained from an excavation near Nocé, in the Perche territory, Normandy. Particles size distribution was quantified by dry sieving for the coarse fraction (above 80 µm), according to French standard NF P 94-056 [NF P 94-056 1996] and by sedimentation analysis for the fine fraction (below 80 µm), according to French standard NF P 94-057 [NF P 94-057 1992]. It is a clayey sand composed of 15% clay, 8% silts, 63% sand and 13% gravels. The soil Methylene Blue Value is 1.05 g/100g and the soil Methylene Blue Activity is 7. Then, according to [Lautrin 1989] the clay fraction of the soil is classified as conventionally active. The raw earth pile is stored outdoor under a plastic tarp. Three samples taken from the pile were used to determine an average water content (w_i) of 26.5% ± 1,5%. For every slips made, the process included sieving with 6mm and 2,25 mm sieves.

Only one type of earth was used. But in order to evaluate the influence of clay fraction variation, sand was added during the slip fabrication process. It is a standard 0/2 mm sand obtained from a quarry near Nocé (Normandy). Indeed, in S0s formulas, sieved earth is used. S0.2s and S2 formulas use a granularly corrected sieved earth with sand at respectively 0.2 and 2 ratios between sand and sieved dry earth (The Fig 3 presents the earth-hemp fabrication process used during the present study. The plan is divided in three parts:

The first box contains the initial data that are compulsory to start the process;
The column on the left presents the fabrication steps, from collecting raw earth to mixing slip with hemp shiv;
The column on the right describes the data that has to be collected from each fabrication step to characterize the batch

Tab 1).

Fig 1 presents the three different used hemp shives (named C1, C2 and C3). C1 and C2 are coming from the same short circuit hemp producer localized near Nocé, in the Perche territory, Normandy. The variety of these hemp shives is Fedora 17. The seeding density was 50 kg.m3 and the harvesting year is 2013. C1 and C2 are coming from same crushing but different sievings. C3 was bought in a conventional building material shop. Hemp shives particles size distribution was measured by automated image analysis. Three different samples were analyzed per shiv to produce a robust statistical characterization based on 700 to 850 particles. The repeatability level is satisfactory: for instance, average hemp length standard deviation between those three pictures was lower than 5%. The Fig 2 shows C1 and C3 have a close particle length distribution, while C2 has much longer particles.

Fig 1. Samples of hemp shives: C1 and C2 are hemp shives from a local hemp producer, C3 was bought in a convention construction shop.

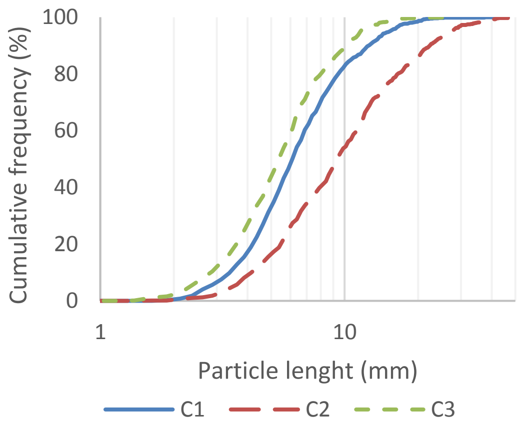

Fig 2. Hemp shives particles size distribution

The Fig 3 presents the earth-hemp fabrication process used during the present study. The plan is divided in three parts:

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Tab 1. Formulations characteristics (C/B stands for the hemp shiv on slip ratio, S/T2 stands for the sand on sieved dry earth ratio)

Reference	Shiv type	C/B	S/T2
C1_F0.26_S0	1	0.26	0
C2_F0.26_S0	2	0.26	0
C3_F0.26_S0	3	0.26	0
C1_F0.26_S0.2	1	0.26	0.2
C1_F0.26_S2	1	0.26	2
C1_F0.4_S0.2	1	0.4	0.2
C1_F0.4_S0	1	0.4	0

2.2 Specimens preparation method

Initial mixtures were prepared with a craftsman, to ensure it is representative of the material used in building works. In the first study, nine formulations were tested (The Fig 3 presents the earth-hemp fabrication process used during the present study. The plan is divided in three parts:

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Tab 1). The first formulation (C1_F0.26_S0) is used as a reference. Then C2_F0.26_S0 and C3_F0.26_S0 allows us to study the influence of the shiv type. C1_F0.26_S0.2 and C1_F0.26_S2 are used to observe the influence of clay fraction variation. Finally, C1_F0.4_S0 and C1_F0.4_S0.2 are made to study the influence of hemp shiv on slip ratio and clay fraction variation.

The clay slip fabrication process is reported in the Fig 3.

First specimens prepared were 10x10x10 cm cubes. Compaction of the material was controlled by defining a wet density. Then, molds were filled up in five layers with equal mass of wet material. In order to compare formulations between them, every specimen presents exactly the same shiv mass. Specimens were unmolded straight after their fabrication, and left to dry in an ambiance controlled room at 23°C, 70% RH. Three specimens of each formulation were weighted every day to draw their drying path.

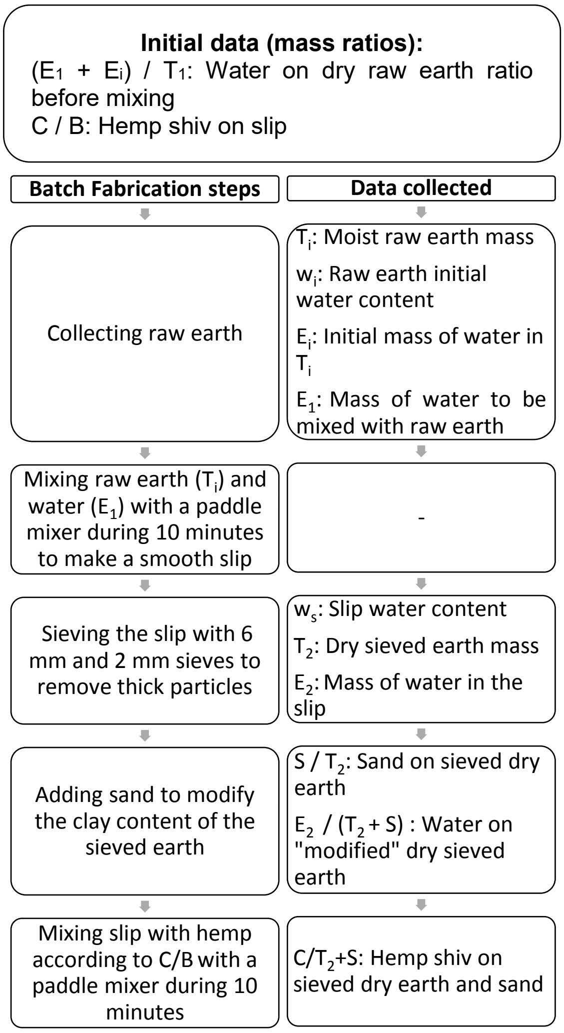

Fig 3. Earth hemp mix fabrication process

Tab 2 presents some physical characteristics of each formulation (slip water content, sand on dry sieved earth ratio, densities and hemp shiv on dry sieved earth and sand ratio). Variabilities due to the fabrication process are the following one:

- The earth-water slip was sieved to remove all the particle above 2,25 mm diameter. Water to earth ratio was modified before and after sieving;
- Made slips shows water content (w_s) variations. Then, the control of the hemp shiv on slip ratio (C/B) does not allow a control on the hemp shiv on sieved dry earth and sand ratio (C/T+S).

2.3 Characterization facilities

Thermal conductivity

The thermal conductivity of material is measured using home-made guarded hot plate device [Carré and Le Gall 1990] in accordance with the NF EN 12664 standard. Samples with dimensions of 10x10x4.8-4.9 cm^3 were dried at 40 °C in ventilated oven until constant weight before testing. Measurement are made at a mean temperature of 23 °C (cold and hot temperature are set respectively to 18 °C and 28 °C). By assuming monodimensionnal heat transfer and negligible contact resistances, heat flow measurement allows assessing the thermal conductivity as:

$$\lambda = \frac{\Phi/S}{(T_{sup}-T_{inf})/e}$$

The measurement uncertainties (±0.5 mm in sample thicknesses, ±1mm in lateral dimensions, ±0.5°C in temperature measurements and ±0.2 mW in dissipated or inlet power) lead to a thermal conductivity uncertainty about 7% [Carré and Le Gall 1990].

Simple compression

Tests were carried out with an Instron 8803 press, with a 100 kN stress sensor. Strain is measured with the plate displacement. Cubic specimens, once dry, were put during 48h in a 40°C chamber, according to the French Hemp building rules [Construire en chanvre 2010].

Tab 2. Specimens fabrication results. W_s is the slip water content, S / T2 stands for sand on dry sieved earth ratio, C / (T2+S) is the hemp shiv on dry sieved earth and sand ratio.

Reference	Ws (g/g)	S / T2	Slip density (kg/m³)	C / (T2+S)	Wet density (kg/m³)	Dry density (kg/m³)
C1_F0,26_S0	2.1	0.0	1249.2	0.8	648.0	341.6
C2_F0,26_S0	2.3	0.0	1240.8	0.9	648.0	337.9
C3_F0,26_S0	2.1	0.0	1249.2	0.8	648.0	327.9
C1_F0,26_S0,2	1.7	0.2	1300.4	0.7	648.0	340.0
C1_F0,26_S2	0.8	1.9	1525.4	0.5	648.0	412.2
C1_F0,4_S0,2	1.7	0.2	1300.4	1.1	470.0	268.5
C1_F0,4_S0	-	0.0	-	-	470.0	271.7

While cylinder is the main used shape for simple compression, using cubic specimens allows a multi-directional mechanical characterization. Youssef [Youssef et al. 2015] published a comparison of mechanical behavior of compressed lime-hemp cylinders and cubes. The geometry of the specimen greatly influences its mechanical behavior, but ultimate compressive strength stays the same. Presented results show that there is no scale influence between cubes of 7, 10 and 15 cm on simple compression strength.

3 RESULTS AND DISCUSSION

3.1 Drying path

Drying path are presented in Fig 5 and 6. As specimens dry masses are not known, water contents cannot be calculated. Thus, results are presented in terms of mass loss. Influence of hemp shives, ratio and sand content are analyzed respectively in Fig. 4, 5 and 6. For the presented specimens, drying state, i.e 24h mass variation inferior to 0.1%, was reach after around 50 days (Fig 5). Drying curves present two linear phases: drying and stabilizing. All the mixes switch to the stabilizing phase after eight hundred hours.

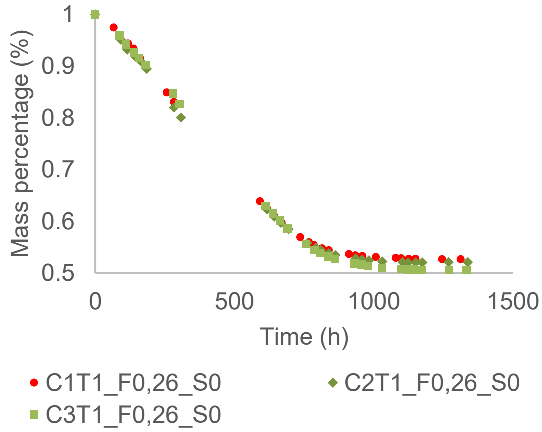

Fig 4. Drying curves of formulas with hemp shiv type variations

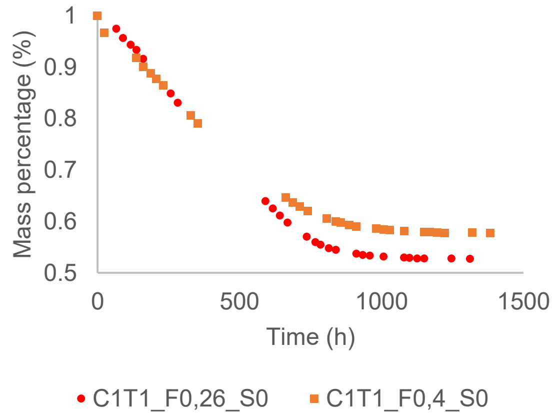

Fig 5. Drying curves of formulas with hemp shiv on dry sieved earth and sand ratio variation

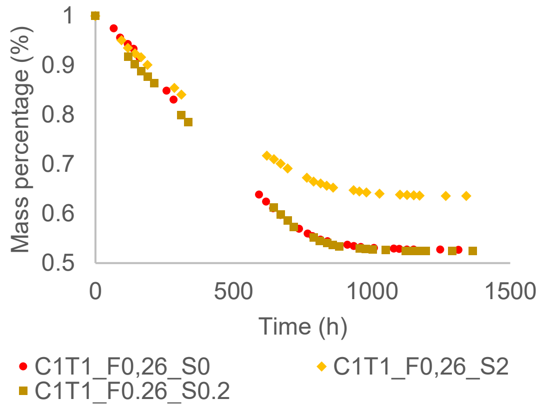

Fig 6. Drying curves with sand on dry sieved earth ratio variations

According to Fig 4, hemp shiv type variation does not have an influence on the drying path. Fig 5 shows that a formulation with more hemp, and so a lower density (see C1_F0,4_S0 and C1_F0,4_S0,2 in Tab 2), has less mass/water to lose, but it does not induce a reduction of the time needed to reach the drying stabilization. Fig 6 confirm this result, as the S2 formula contain less water than the S0 one. This conclusion is valid within the range of volumetric mass range tested (270 – 415 kg/m^3 dry density)

3.2 Thermal conductivity

Results of thermal conductivity are presented in Fig 7. A good level of repeatability was observed for some mixes (C1_F0.26_S0.2, C1_F0.4_S0.2, C1_F0.26_S0 and C1_F0.4_S0). But three mixes (C2_F0.26_S0, C3_F0.26_S0 and C1_F0.26_S2) show an important standard deviation: for a similar bulk density, thermal conductivity can range from 0.096 to 0.132 W.m^{-1}.K^{-1}.

Our results show:

- Shiv type does not seem to affect the thermal conductivity as observed differences lie in standard deviations;
- Influence of the earth nature (due to the addition of sand) is not clear. Surprisingly, at comparable bulk densities, mixtures with added sand have a lower thermal conductivity, while sand as a thermal conductivity higher than clay/silt (λ_{sand}=2.000 > $\lambda_{clay/silt}$=1.500 W. m^{-1}.K^{-1}) [Courgey and Oliva 2001];
- Unsurprisingly, the higher the hemp shiv on dry sieved earth and sand ratio, the lower is the material density, and thus the lower is the thermal conductivity.

Earth-hemp results are compared with lime-hemp characterizations from previous studies, performed exclusively with permanent measure methods:

- [Cerezo 2005]: Guarded hot boxes
- [Collet 2004]: Hot Plate
- [Amziane and Arnaud 2013]: Guarded hot boxes

3.3 Mechanical behavior

Fig 8 shows the curves of a simple compression tests on mix C1_F0,26_S0. As presented by Tronet on lime and hemp concrete [Tronet et al. 2016], three phases are observed :

1. A very short pseudo elastic area;

2. An elasto-plastic deformation zone;

Data were analyzed thanks to a graphic lecture developed in the paper of Tronet [Tronet et al. 2016] to obtain the maximum stress before irreversible deformations (σ_y) and the apparent elastic Young modulus (E_c).

Our results show that yield stress (0.3 MPa) and elastic modulus (9 MPa) are similar to lime hemp results from the literature. Indeed, at comparable dry densities between 360 kg/m^3 and 460 kg/m^3, a yield stress between 0.29 MPa and 0.39 MPa was found on 10 cm cubic lime hemp specimens [Walker, Pavia, and Mitchell 2014] and an elastic modulus between 9 MPa and 44 MPa was found on 16x32 cm cylindrical lime hemp specimens [Cerezo 2005; Arnaud and Gourlay 2012].

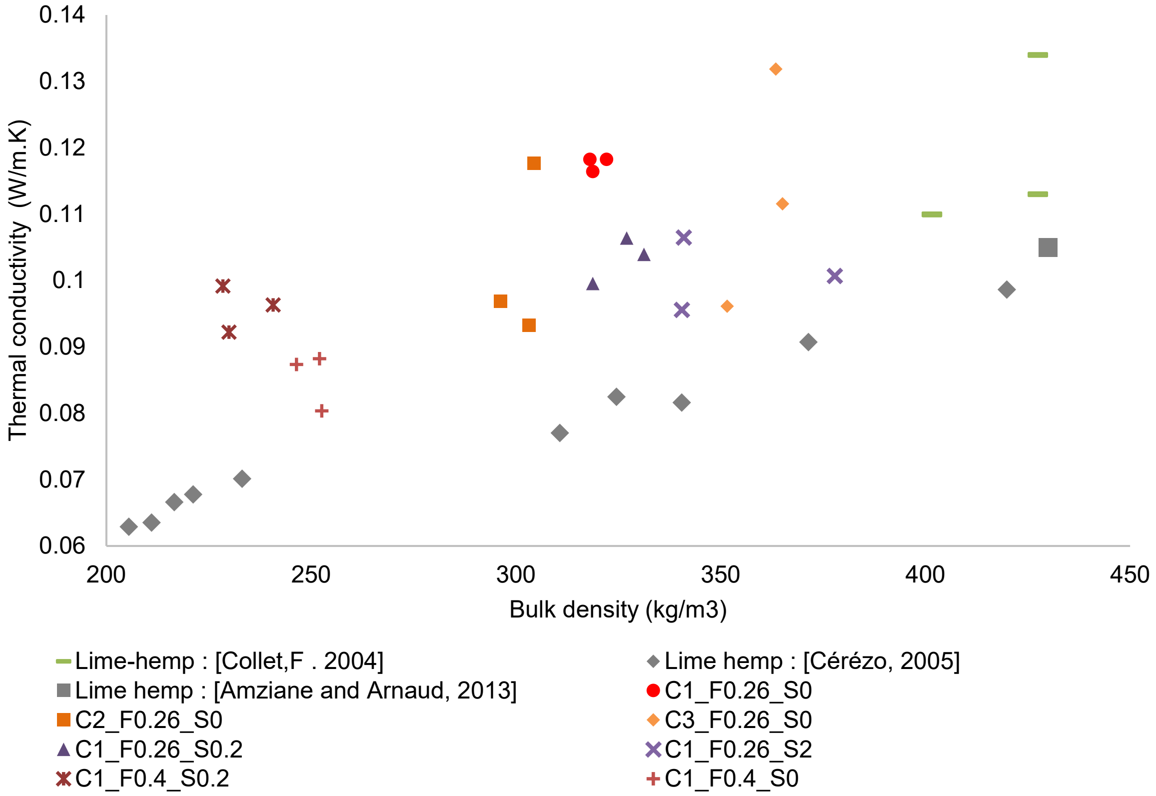

Fig 7. Thermal conductivity values of present study formulas and literature

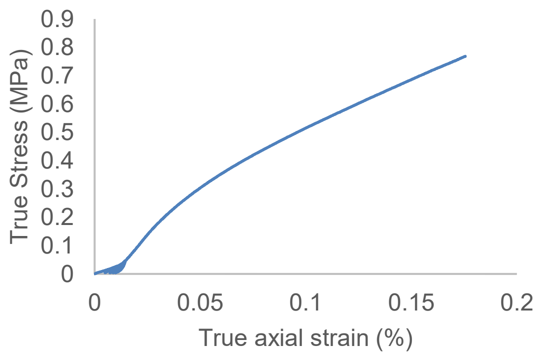

Fig 8. Stress strain curve of a C1_F0.26_S0 specimen

4 CONCLUSION

These preliminary results highlight the similarity between earth-hemp and lime-hemp insulation materials, regarding thermal conductivity and compression resistance. Even if not enough mechanical resistance tests were performed to draw definite conclusions, the preliminary results obtained shows earth-hemp might comply with the requirements of the French hemp building rules criteria for lime-hemp construction [Construire en chanvre 2010].

Additional thermal hydric and mechanical characterizations are currently being performed. In addition, new mixtures are being prepared, modifying the sample preparation (casted, sprayed), the component nature or the mixtures recipe. These results would be analyzed in light of the feedback of real building thermal insulation with earth-hemp from the last five years, and of the building works that would be performed in parallel of the Eco-Terra R&D project.

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