EXPERIMENTAL ASSESSMENT OF HYGROTHERMAL PROPERTIES OF CLAY – SUNFLOWER (HELIANTHUS ANNUUS) AND RAPE STRAW (BRASSICA NAPUS) BIO-COMPOSITES

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Abstract
The purpose of this investigation is the experimental characterization of the hygric and thermal properties of four clay/vegetable aggregates mixtures. In order to evaluate the hygrothermal behavior of these biocomposites based on different aggregates, moisture buffer value, sorption/desorption isotherm and thermal conductivity were investigated here. This work is carried out in the framework of the BIOCOMP project which aims to develop those locally produced biocomposites to be used as building's interior insulating plasters. This, to offer refurbishment solutions for vernacular buildings in Touraine, Center of France. Sunflower stem and rape straw are considered as agricultural byproducts aggregates whereas local clay is used as binder. In this study, the samples were prepared with the following vegetables: rape straw, sunflower bark, sunflower pith and a mix of sunflower pith and bark. For a same binder:aggregates and water;binder weight ratio, we obtained samples with different densities and different properties depending on the aggregates. The hygric and thermal performances of those mixtures make them competitive in comparison to hemp-lime concrete and could therefore offer a wider variety of refurbishment solutions having a low embodied energy.

Keywords:
Agricultural byproducts, clay plaster, lightweight crude earth, sunflower, rape straw, MBV.

1 INTRODUCTION

Implementation of ambitious actions towards the global warming threats beginning to emerge in the building and construction's sector. This appears to be relevant when we consider that this sector is responsible of 1/3 of global greenhouse gases emissions [International Energy Agency 2013].

To reach the "below 2°C" global warming pathway, a Global alliance have been created during the 21st Conference Of Parties in Paris in December 2015. One of its main objectives is reaching a 50% reduction of greenhouse gases in the building sector by 2050.

In France, a focus has been made on the refurbishment needs in a strategic energy transition plan, with the very ambitious target of 500,000 buildings renovations per annum. In this plan, other ambitious quantified guidelines of 50% greenhouse gases reduction by 2030 and 87% reduction by 2050 have been stated.

To help meeting those objectives, low carbon construction processes are encouraged by public project owners. A low carbon building label that will prefigure the next public regulation has been implemented in France in 2016 as a pilot phase. It recommends among others, carbon storing materials and encourage circular economy. Consequently, build and renovate with biobased materials having undergone little transformation like crude earth and vegetable aggregates are thus an environmentally appropriate approach. Those materials should now demonstrate their interest in terms of performances and durability. That is the purpose of the work being held in the biocomp project with partnerships involving local communities, group of farmers, bioconstruction masons and two universities: Polytech Tours and Polytech Orléans.

Clay/plant aggregates and fibers started to be investigated lately [Laborel 2016] but few studies can be found concerning earth plasters [Navarro 2015]. For many of those studies, vegetables are considered as reinforcement for earthen materials to avoid shrinkage. In the biocomp project, crude earth is used to bind the aggregates in small quantities in order to reach low density mixes (200 to 800kg.m^{-3}). The purpose of this present work is to provide data about thermal conductivity against densities and used aggregates on one hand and moisture buffering as well as sorption/desorption properties on the other hand. We then position those materials to similar ones that could be hemp concretes, rape-straw concretes or lightweight's earthen materials.

2 MATERIALS

2.1 Aggregates

The vegetable aggregates used in this investigation are rape-straw and sunflower stem. Both are considered as by-products as those crops are cultivated for their seeds to produce canola and sunflower oil. Those plants' straws and stems have no other use but being buried in the fields as organic soil amendment. The sunflower stem is composed by a rigid external part (bark) and a lightweight inner part (pith) see Fig 1 and 2. This pith has an honeycomb structure with large pores' size similar as the one observed for corn pith [Palumbo 2015].

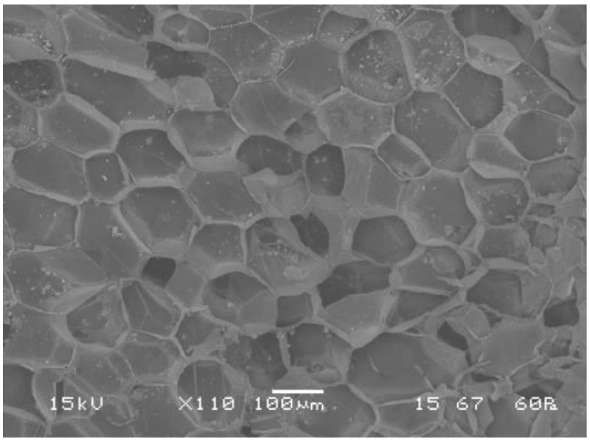

Fig. 1: SEM picture of sunflower pith

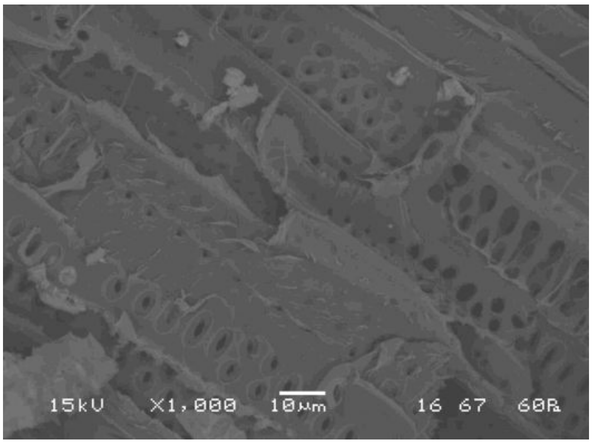

Fig. 2: SEM picture of sunflower bark

The sunflower stem enabled us to use 3 different aggregates by separating its components: pure bark, pure pith and a mix of bark and pith this last one with the same density as the used rape-straw. Those vegetables were grinded with a Retsch SM100 knife mill using a 15mm grid. We had to remove the dust off the bark aggregates using a 2mm sieve.

2.2 Binder

The crude earth is excavated from a local quarry. This little factory used to be a production site of refractory bricks for bakery ovens in the beginning of last century. The high amount of clay of this crude earth and its lightness due to the presence of kaolinite naturally brings markets for art pottery and ceramics as well as for biobuilders who use it for finish earth plasters. They have therefore all the equipment in their production site to crush and sieve the raw excavated crude earth. The granulometric analysis (sieving and sedimentation) revealed us the following grain size proportions: 35% clay, 40% silt and 25% sand. The clay composition (kaolinite, montmorillonite, nontronite) has been characterized by X-Ray absorption.

2.3 Formulation and manufacturing

We investigated the hygric properties of those mixes at the same 2.4:1 binder:aggregates and 1:1 water:binder weight ratio. The significant differences in aggregates' densities and the variation of compaction strength used during the molding led to huge variations in samples' densities (see Tab. 1). We also have to notice that using the same water:binder ratio for such different aggregates leads to different mixtures' homogeneity as it has also been noticed by Palumbo and Navarro [Palumbo 2016] [Navarro 2015] and the compaction strength had to be modified to reach good enough workability.

Crude earth and water were first mixed together at a 1:1 ratio after what we waited 10 min before adding the aggregates in order to let the clay being sufficiently hydrated. By modifying the compaction strength using a Zwick/Roell Z010 press we were able to reach different fresh densities in cylindrical molds. The demolded samples have then been dried in a 23°C 50%HR regulated climatic chamber. Cylindrical samples of 11cm diameter and 6cm thickness were produced for MBV's experiments see Fig.3, other molds of 5x5x4cm for sorption/desorption purpose and another 11x5x4cm for thermal conductivity measurements has also been used.

Fig. 3: Samples from left to right (SP, SBP, SB and RS)

Tab. 1: Dry mortar densities of different clay/vegetable aggregates mixtures

Clay/aggregate sample	Aggregate	Dry mortar Density (kg/m^3)	Binder/aggregates weight ratio	Aggregates/binder volume ratio
RS	Rape Straw	438.24	2.4	7
SBP	Sunflower bark and pith	512.42	2.4	7
SB	Sunflower Bark	714.38	2.4	4.7
SP	Sunflower Pith	235.05	2.4	26

3 EXPERIMENTAL METHODS

3.1 Thermal conductivity.

We measured the thermal conductivity at dry state (the samples were oven dried at 60°C for 24h). The measurement was realized by using the hot-wire technic following the ASTM D5930-97 standard. We used a NEOTIM FP2C conductivity meter equipped with hot wire sensor placed between 2 samples of similar geometry Fig.4. The thermal conductivity was then the average value of its pair within 5 to 7 values.

Fig. 4: Hot wire NEOTIM FP2C conductivity meter with SP sample

3.2 MBV measurements.

The practical Moisture Buffer Value (MBV) measured here characterizes the hygric behavior of the materials when they are exposed to periodical variations of relative humidity in a KBF 240 climatic chamber Fig.5. In our case 3 samples for each formulation were submitted to 75%RH during 8h and 33%RH during 16 hours. This dynamical characterization of the moisture buffering capacities of the materials pretends to simulate indoor climate variations during day and nights and then its ability to regulate indoor climate.

We followed the Nordtest protocol [Rode 2007], cylindrical samples of 16cm diameter and 6cm thickness were realized and sealed with aluminum tape on all but one side in order to get an exposed area of 0,02m^2. The air fans velocity was reduced to 10% of its maximum value and samples weren't exposed to the direct air flow. Nevertheless, since anemometric measurement haven't been carried next to the samples, the obtained MBV values could be overestimated. After having carried out 4 cycles, the weight amplitude did vary less than 0.20% from the last 3 days before we stopped the experiment. The unit for MBV is g/(m^2.%RH). The practical MBV has been calculated using the following equation:

$$MBV = \frac{\Delta m}{A.(\%RHhigh - \%RHlow)} \tag{1}$$

Where Δm is an average of the adsorbed and desorbed mass after the system has reached a dynamic equilibrium (g) and A is the exposed surface area (m^2).

Fig. 5: Samples in Binder KBF climatic chamber

3.3 Sorption/desorption

Sorption/desorption isotherm have been drawn for SBP, SB and RS using salt cup method. To control the relative humidity of the environment, the samples were stored into desiccators containing different mineral salts. Relative humidity rates used for this study are 12, 33, 44, 55, 66, 76, 86, 93 and 98 %. In order to determine the sorption curve, the different samples were first oven-dried (60°C for 24h) before being placed in the corresponding desiccators. In parallel, the other half of the samples were water-saturated by pouring water on them using a wash bottle (this method was employed because the samples tends to disintegrate when immersed in water) and stored in other desiccators at the same relative humidity.

4 RESULTS

4.1 Thermal conductivity

We plotted in Fig.1 the measured thermal conductivities and densities of the tested samples. In order to compare with other data found in literature for vegetable concretes, we plotted on the same figure the empirical relationship established by Cerezo Eq.2 [Cerezo 2005] for lime/hemp concretes for densities ranging from 200 to 800 kg.m^{-3}. This relationship was in good agreement with clay/straw mixtures experimental results found by Labat [Labat 2016] and the behavior is similar to our results. Our samples present though lower values of thermal conductivities for densities lowers than 500 kg.m-3. On the contrary, SBR samples experimental results at ρ=700kg.m^{-3} are very close to the empirical relationship see Fig.6.

$$\lambda = 0.0002 * \rho + 0.0194 \tag{2}$$

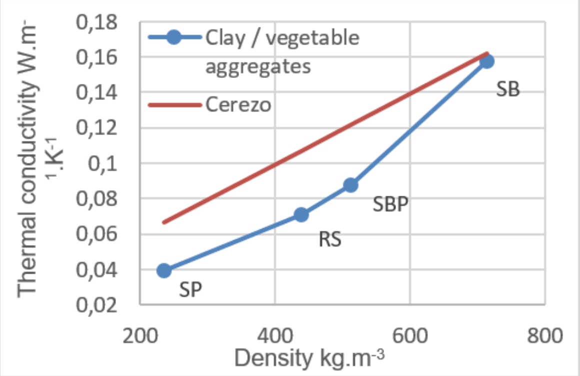

Fig.6: Dry mortar thermal conductivities and densities of clay/vegetables samples

In this project, the focus has been made to reduce the amount of binder to reach lightweights plasters comparison with other studies concerning earth/vegetable aggregates or fibers [Palumbo 2016], [Lima & Faria 2015] which dealt with higher density materials. Labat [Labat 2016] did study lightweights straw/clay mixtures from 200 to 800 kg.m^{-3} and reach higher thermal conductivity values closer to those expected by Cerezo's relationship.

4.2 Moisture buffer value

Crude earth is known as a very good hygric regulator. Furthermore, it has been observed that the addition of aggregates like corn pith improved the moisture buffering [Palumbo 2016]. As expected the MBV of our mixtures is then higher than 2 g/(m^2.%RH) see Tab.2

and can be classified as excellent according to the classification proposed by Rode [Rode 2007].

Tab. 2: Practical Moisture buffer values of the tested samples

Clay/aggregate sample	MBV g/(m^2.%RH)
RS	3.5
SBP	3.3
SB	3.2
SP	2.9

We can notice that density doesn't seem to have a direct impact in terms of moisture buffering values as observed by McGregor for other earthen materials [McGregor 2014] see Fig.7.

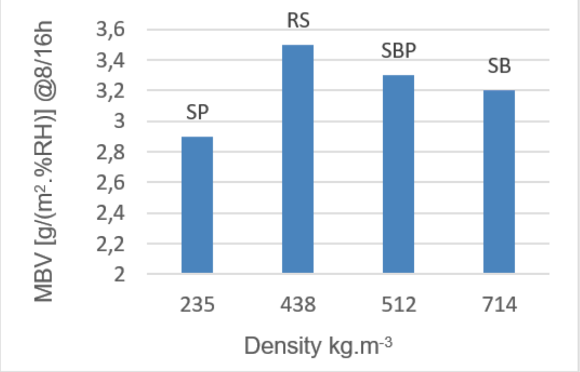

Fig.7: Comparison of Practical MBV determined on the present test with other materials following NORDTEST protocol.

4.3 Sorption/desorption

The sorption/desorption curves were drawn for RS, SBR and SB see Fig.8. All three mixtures show similar behavior and mass water content during the sorption phase. Nevertheless, while SBP still show similar desorption behavior with RS between 30 and 76%HR, SB do store less mass water content at this range of relative humidity leading to smaller hysteresis.

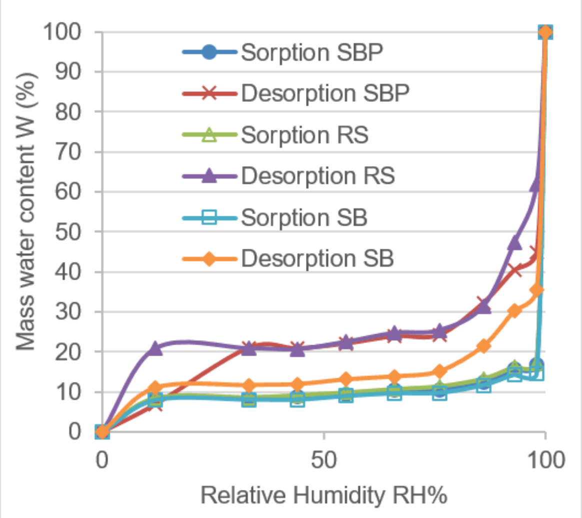

Fig. 8: SB, SBP and RS sorption/desorption isotherm

5 CONCLUSION

It has been confirmed in this study that clay/vegetable aggregates mixes do reach higher performances in terms of moisture buffering than hemp concretes [Oudhof 2015]. Knowing that crude earth proportions were minimized, and that the used clay contains kaolinite that is known to absorb less water vapour than other types of clays like bentonites [Liuzzi 2013], those moisture buffering properties could be optimized if wanted by modifying the formulation.

The formulations allow here to reach low densities insulating plasters in order to get better performances in terms of thermal conductivity. As expected, the optimal results with thermal conductivity values below 0,040 W.m^{-}K^{-1} were obtained by using sunflower pith, a very lightweight aggregate. According to NF P 75-101 standard, these values could allow to classify this material as insulating plaster and not thermal corrector anymore. Thus, further characterizations both at material and wall scales must be performed to fully evaluate those materials' properties.

According to the plant aggregate that will be chosen, the clay mineralogy and ratio used, a large variety of materials can be elaborated both for refurbishment and new construction needs.

6 ACKNOWLEDGMENTS

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