Energy and Buildings 88 (2015) 91–99

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Characterization of flax lime and hemp lime concretes: Hygric properties and moisture buffer capacity

M. Rahim [a], O. Douzane [a], A.D. Tran Le [a], G. Promis [a], B. Laidoudi [b], A. Crigny [b], B. Dupre [b], T. Langlet [a,*]

[a] Innovatives Technologies Laboratory (LTI), University of Picardie Jules Verne, Avenue des Facultés - Le Bailly, 80 025 Amiens Cedex 1, France
[b] CoDEM Picardie, 41 Avenue Paul Claudel, DURY, 80480 Amiens, France

ARTICLE INFO

Article history:
Received 20 May 2014
Received in revised form 8 October 2014
Accepted 16 November 2014
Available online 9 December 2014

Keywords:
Flax lime concrete
Hemp lime concrete
Hygric properties
Moisture buffer capacity
Moisture penetration depth

ABSTRACT

Bio-based materials are increasingly recommended because they have a low environmental impact and correspond perfectly to high environment quality buildings. This article presents the moisture properties of a new bio-based material called flax lime concrete (FLC) and of hemp lime concrete (HLC), which is used to validate the experimental protocol of this work. The moisture properties (sorption isotherm, water vapor permeability, moisture diffusivity) and moisture buffer capacity estimated from the moisture buffer value were determined to gain knowledge about the behavior of these materials under equilibrium and dynamitic conditions. The results showed that both bio-based materials have high hygric performance and exhibit an “excellent” moisture buffer capacity according to the classification proposed by the Nordtest project.

1. Introduction

The building sector accounts for about one-third of the primary global energy demand that represents a major source of energy-related greenhouse gas emissions. An increased environmental awareness incites to use “green” and “high thermal performance” building materials in terms to reduce energy and raw materials consumptions. The valorization of plant resources as building materials or incorporating construction processes has been carried out in the past few decades. One of these building materials is hemp lime concrete (HLC), which has been extensively studied in many researches [1–4]. The results showed that this material has advantageous characteristics as a moulding material, despite insufficient mechanical performance to make a load-bearing material [1,5]. Hemp concrete is increasingly recommended because it has a low environmental impact and corresponds perfectly to High Environment Quality Buildings [6,7]. The life-cycle analysis of this material, proves that it has a very low carbon footprint. Concerning the hemp concrete case, it stores 0.35 kg CO_2 eq./UF/year [8], while other building materials such as brick emit more than 0.49 kg CO_2eq./UF/year. The physical and hygrothermal characteristics have shown that this material has a low conductivity, which reduces heat diffusion and a high moisture buffering capacity which can maintain indoor hygrothermal comfort [5,9,3,2]. Previous studies indicate that the dry thermal conductivity is about 0.1 W/(m K) [10,11]. From a hygric point of view, hemp concrete has a high moisture transfer (its water vapour permeability is approximately 2.5×10^{-11} kg/(m s Pa)), storage capacities and high moisture buffer value (2.15 g/(m^2 %RH)) [2]. At whole building level, numerical and experimental results showed that hemp concrete can decrease the daily indoor relative humidity variations and reduce energy consumption [12–14].

However, beside of the hemp lime concrete which has been extensively studied, various aggregates derived from plant such as straw-clay [15], flax shives [16], diss [17], a fibrous plant which grows in wild state around the Mediterranean, can be used. This study will concentrate on a sustainable and green concrete called “flax lime concrete” by combining the flax shives (which are considered as waste products) with a lime-based binder. Indeed, using flax shives as green materials will help to promote new economic prospect for flax by products in France where the annual production of flax shives is abundant (about 230,000–260,000 tons) [18].

In a previous study [16], experimental measurements have shown that the thermal conductivity of flax concrete is slightly higher than that of hemp concrete (respectively 0.17 W/(m K) and 0.12 W/(m K)); however, the insulating power of these two materials is much higher than ordinary concrete. But despite having a low mass density (598 and 478 kg/m^3 for flax and hemp

* Corresponding author. Tel.: +33 0322534043; fax: +33 0322951751.
E-mail address: thierry.langlet@u-picardie.fr (T. Langlet).

http://dx.doi.org/10.1016/j.enbuild.2014.11.043
0378-7788/

Nomenclature

λ	thermal conductivity (W/(m K))
MBV	moisture buffer value (g/(m^2 %RH))
w	water content (kg/m^3)
m	mass (kg)
V	volume (m^3)
RH	relative humidity (%)
φ	relative humidity
δ_p	water vapour permeability (kg/(Pa m s))
g_v	moisture flux (kg/(m^2 s))
ΔP_v	vapour pressure gradiant (*Pa*)
e	thickness (m)
D_w	moisture diffusivity (m^2/s)
P_s	saturation vapour pressure (Pa)
$\frac{dw}{d\varphi}$	specific hygric capacity(kg/m^3)
A	surface (m^2)
PP	penetration depth (m)
t_p	period (s)
b_m	moisture effusivity (kg/(m^2 Pa s$^{1/2}$))
μ	vapour resistance factor

concretes respectively), which reduces their storage capacity, their density remains higher than traditional insulation materials. Nevertheless, both thermal and moisture properties are necessary to understand the hygrothermal behavior of these materials under climate conditions. Therefore, this article presents a moisture characterization of two bio-based materials: hemp concrete and flax concrete. Hemp concrete is the reference material, which is used to validate the experimental protocol by comparing the results to the work published by others. Also, the comparison of these two materials intended to provide more information about the flax concrete which is the main subject of this study. These materials were tested for moisture properties (sorption isotherm and water vapour permeability) and moisture buffer values inspired by the Nordtest project [19] which represent their ability to dampen the indoor relative humidity variations thanks to their sorption capacity.

2. Materials

The two innovative building materials studied are hemp lime and flax lime concretes, which can be used in both renovated and new buildings. Hemp lime concrete is comprised of water, lime-based binders and hemp shives (granular of hemp descended from the inner woody core), while flax-lime composite is made out of flax shives (woody core of industrial flax stalk) mixed with binders and water. Experimental results suggested that hydrate lime is the most appropriate binder to implement hemp concrete [3]. Thus, the binder used for the formulation is Tradical PF 70 containing a hydrated lime base (CL-90S), hydraulic and puzzolan binders. The proportions of lime binder, hemp/flax shives and water by volume is presented by Table 1. The water input was primarily studied in order to ensure the workably of the mixture.

Specimens were produced and prepared in the laboratory. Hemp and flax shives which have a relatively constant size distribution (5× 5 × 15 mm for hemp shives and 0.5∅ 10 mm for flax shives), were collected from the companies around Amiens, France. The aggregates and binder were combined to ensure a better mix of concrete. Water was added after which the material was mixed for a few minutes until complete homogeneity was obtained, each one was manually filled in the mould and then damped in order to avoid the empty zone. Once filled, the moulds were placed in a room with high humidity conditions (90% of relative humidity and 18 ° C for temperature). The concrete specimens were then removed from the mould after three days and the samples are stored in the same location for 9 months in order to ensure the total carbonation of the concrete as recommended in Cerezo's work [5]. Furthermore, the mechanical behavior is influenced by the age of concrete, the curing conditions, the kind and the content of binder, and hemp shives characteristics [1]. By observation, it should be noted that, the both materials are quite homogeneously distributed.

Table 1
Proportion of lime binder, hemp/flax and water by volume for concretes.

	HLC	FLC
Granular	64%	68%
Lime	12%	10%
Water	24%	22%

Table 2
Density and porosity of studied concretes and aggregate.

		HLC	Hemp shives	FLC	Flax shives
Dry density	[kg/m^3]	478 ± 7	125 ± 9	598 ± 4	90 ± 5
Matrix density	[kg/m^3]	2030 ± 30	1259 ± 21	2038 ± 10	1270 ± 55
Open porosity	[%]	49.9 ± 2.0	–	48.2 ± 1.2	–
Total porosity	[%]	76.4 ± 0.1	90.1 ± 0.5	70.6 ± 0.3	92.9 ± 0.7

Before measuring of hygric material properties (sorption isotherms, water vapour permeability and MBV value), dry density, matrix density and porosity of concretes and aggregates were carried out. The matrix density is measured experimentally according to the pycnometer method which involves filling air spaces in material with toluene. The total porosity is determined from the matrix density and dry bulk density of material. Regarding the open porosity, it is determined from according to the vacuum saturation method.

The matrix density and dry bulk density of studied materials are presented in Table 2. The results show that hemp and flax shives are fibrous materials and present an important porosity (90.1% and 92.9% respectively). Concerning the concretes, FLC shows a lower porosity than that of HLC (70.6% compared to 76.4%) and a higher dry density (598 compared to 478 kg/m^3).

When Scanning Electron Microscopy (SEM) analysis of hemp and flax particles was performed (see Fig. 1), the results showed that flax shive has a finer and more homogeneous porosity when compared to hemp. The pores are of different sizes; their diameters are about 15 μm and 10–40 μm respectively of the flax shives and hemp shives. For hemp case, this observation is in accordance with the porous structure analysis performed by Collet et al. [20].

3. Theory and method

3.1. Sorption isotherm

The sorption isotherm or the hygroscopic curve describes the equilibrium between the water content of material and relative humidity of the surrounding air. In this article, the isothermal sorption curves were measured according to discontinuous method. The sorption isotherms were obtained by measuring the moisture content of test specimens in accordance with standard NF EN ISO 12571 [21]. The samples are cylinders of 10 cm diameter and 3 cm thickness. The dry density of HLC and FLC are 482± 15 kg/m^3 and 603± 12 kg/m^3, respectively.

The test room temperature is maintained at 23° C by an air conditioner. The specimens were then placed in test chambers with saturated salt solutions in order to keep relative humidity at desired levels which have been chosen: 0%, 33%, 51%, 75%, 81% and 95%. For each measuring point, three samples were used. The samples were dried in an oven at 70° C until a stable mass was reached. The water