HYGROTHERMAL PERFORMANCE OF HEMPCRETE FOR ONTARIO (CANADA) BUILDINGS

Ujwal Dhakal, Umberto Berardi, Mark Gorgolewski, Russell Richman

ABSTRACT

Hempcrete is a bio-aggregate based composite material used for building envelopes which typically consists of hemp shiv (hurd), lime binder and water. It has several distinct advantages including low thermal conductivity, effective moisture buffering, and high sound absorption, while having a high carbon sequestration "index". This work investigates the impact of mix proportions on hempcrete properties and the hygrothermal performance of two proposed hempcrete wall assemblies for Ontario, Canada. The experimental results highlight the significant influence of the binder on the density and thermal conductivity of the final material. Thermal conductivity measurements ranged from 0.074 to 0.103 W/mK. Finally, hygrothermal analysis demonstrated that when using hempcrete in the Canadian climate a rain screen wall system is more suitable than a mass wall.

INTRODUCTION

Hempcrete is one such bio-aggregate-based, natural building material which has potential for use as a thermal and acoustic insulation system (Arnaud and Amzaine, 2013). It typically consists of hemp shiv (hurd), lime binder, and water. Hempcrete has a low effusivity and a high thermal inertia, so it does not take as long to warm and once heated; it slowly releases the heat when the surrounding temperature drops (Evrard, 2008). For this reason, hempcrete has been proposed for use as a thermal insulator, although not an exceptional one (Arnaud and Amzaine, 2013). Today residential hemp construction projects are permissible under Section 9 of the Ontario Building Code as alternative solutions (Kenter, 2015).

There are essentially no industry standards for hempcrete at this time; however, some manufacturers have established basic rules for their own use. This results in a lack of clear cross-industry references (Stanwix and Sparrow, 2014).

Low thermal conductivity, excellent moisture buffering (MBV >2 g/m^2 %RH), phase changing between liquid and vapor (which maintains much more thermally stable indoor conditions), no risk of "off-gassing" or toxicity during the in-use phase of a building, or at end-of-life demolition, while having a high carbon sequestration "index" are some of the distinct advantages of hempcrete (Bevan and Woolley, 2008; Arnaud and Amziane, 2013; Collet et al., 2013; Ahlberg et al., 2014; Stanwix and Sparrow, 2014). Hempcrete based walls store more carbon (262 kg CO_2e/m^3) than is emitted (127 kg CO_2e/m^3) representing a lifetime net balance of 135 kg CO_2e/m^3 (Arnaud and Amziane, 2013). Further, at the end of its life, the hempcrete can be easily broken down and re-used in a new build, or alternatively, being a natural product, it will break down and contribute lime and organic matter to the land (Hemp Edification,

2015).

RESEARCH METHODOLOGY

The research methodology was comprised with three major actions; literature review, laboratory testing and analysis, and hygrotheral analysis of wall through WUFI modeling. To comprehend the impact on the properties of hempcrete with increasing lime binder, 3 types of mixes (M1, M2 and M3) with a hemp to binder ratio of: 1:1, 1:1.5 and 1:2 respectively were studied by using locally grown Canadian hemp.

LABORATORY TESTS

Laboratory experiments were carried out according to ASTM standards: ASTM C518-10 (Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus), ASTM C67-14 (Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile) and ASTM C62-13a (Standard Specification for Building Brick - Solid Masonry Units Made from Clay or Shale). All tests were performed after 26 days of natural drying which is when density/mass was stabilized. Following table (Table 1) highlights the summary of overall test results.

Table 1: Test measurements

Mix	Dry Density (ρ_0) (kg/m^3)	Dry Thermal Conductivity (k_0) (W/mK)	Porosity (Φ) (m^3/m^3)	Free Water Saturation (W_f) (kg/m^3)	Maximum Water Content (W_{max}) (kg/m^3)	WC at 80% RH ($MC_{80\%\ Equiv}$) (kg/m^3)	Saturation Coefficient (-)	Typical built-in (Initial) MC (kg/m^3)
	(ASTM C67)	(ASTM C518)	(ASTM C67)	(ASTM C67)	(ASTM C67)	(ASTM C67)	(ASTM C62)	(ASTM C67)
1	233.03	0.074	0.53	376.29	532.66	17.47	0.71	259
2	316.79	0.088	0.53	374.96	525.66	23.17	0.71	257
3	387.74	0.103	0.66	423.55	655.31	29.08	0.65	286
*σ	77.44	0.015	0.075	27.68	72.92	5.81	0.035	16.2

σ = Standard Deviation

Dry density of hempcrete was linearly related to the proportion of binder; when binder was increased by 50% and 100%, density increased by ≈ 36% (Mix 2) and 67% (Mix 3) respectively. Similarly, dry thermal conductivity of hempcrete maintained a near linear relationship with density; when densities were increased by ≈ 36% and 67%, dry thermal conductivities increased by 18.32% (Mix 2) and 38.12% (Mix 3) respectively (Table 1). Measurement of R value/inch (imperial) was ranged from 1.41 to 1.94.

ONE-DIMENSIONAL HYGROTHERMAL ANALYSIS IN WUFI

To simulate the hempcrete wall (Mix 3) in WUFI Pro 5.3, material inputs were measured from the laboratory tests (Table 1) supplemented with reference values: dry thermal capacity (c_0) = 1560 J/kgK,

dry vapour diffusion resistance factor (μ) = 4.85, thermal conductivity supplement (b) = 3.34 %/%mass and liquid absorption coefficient (A-value) = 0.074 kg/m2/$s^{1/2}$. Hempcrete was inserted into the WUFI material database as a user-defined material with the inputs listed above.

A default WUFI climate file for Toronto, cold year was used for simulation. Values for outside temperature and RH were based on weather file. A user defined sine curve was used to define the inside temperature and RH referring to a typical interior environment in residential buildings (T 21±1^{0}C, RH 50±10%). Simulation was conducted for 3 years period. Two types of wall assemblies as shown in Figure 1 were simulated, with and without exposure of rain, wind and sun.

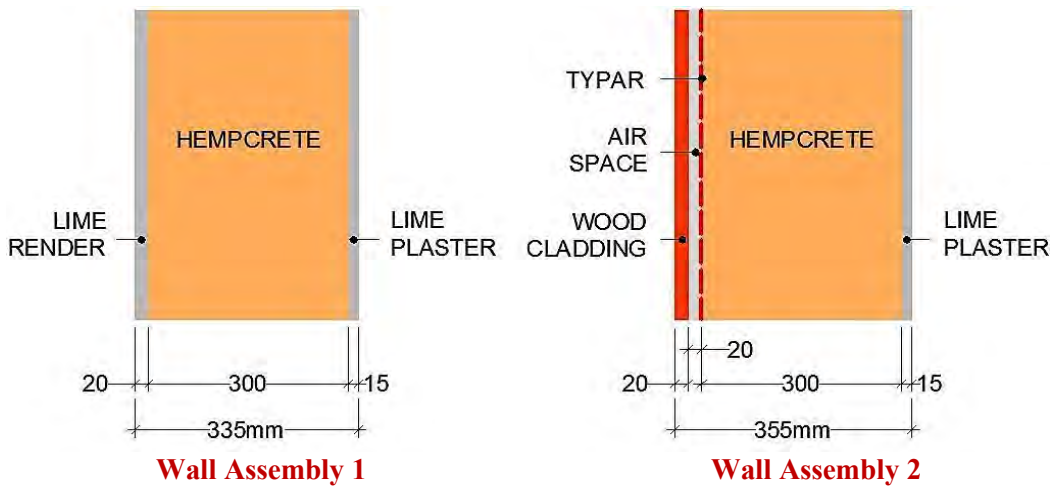

Figure 1: Simulated wall assemblies

Further, to detect the most influential factor on the hygrothermal properties of hempcrete, a, series of (four) sensitivity analyses were also conducted by using referenced material properties (moisture sorption and thermal conductivity) for wall assembly 1 (Base case).

1) Sensitivity Analysis 1: Using reference moisture sorption values: Porosity= 0.73 m^3/m^3, $W_{80\%EQUIV}$ = 33 kg/m^3, W_{max}= 730 kg/m^3 and W_f =546 kg/m^3; to understand the impact of water content in the performance of hempcrete wall.

2) Sensitivity Analysis 2: Using a reference dry "k" value= 0.115 W/mK (high) and moist "k" value= 0.768 W/mK to understand the impact of high "k" value.

3) Sensitivity Analysis 3: Using a mid-level reference dry "k" value= 0.09 W/mK to understand the influence of intermediary thermal insulation.

4) Sensitivity Analysis 4: Using a low-level reference dry "k" value= 0.06 W/mK to understand the hygrothermal behavior of wall in high thermal insulation scenario.

No change has been made in boundary conditions, climate file, orientation and assumptions from base case.

SIMULATION OUTPUTS

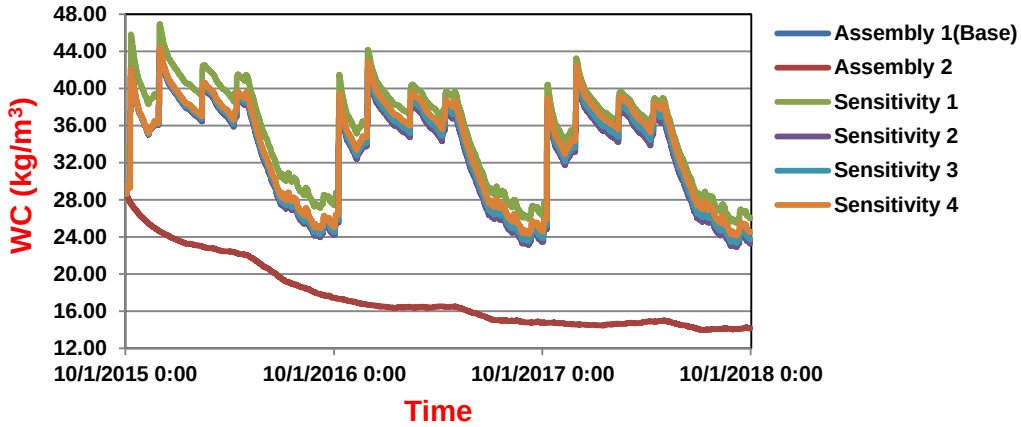

Figure 2: Water content in hempcrete - Assembly 1 (mass wall), Assembly 2 (rain screen wall) and Sensitivity analysis

WUFI analysis shows both the wall assemblies (face-sealed mass wall and vented rain screen system) are performing well without any hygrothermal risks such as condensation, frost and salt damage and mould growth. However, when comparing the two assemblies vented rain screen is performing significantly better from a hygrothermal perspective. Figure 2 and Table 2 further highlight the benefits of a vented cavity in the Toronto climate as water content in the hempcrete notably dries out when vented (water content 3.60% to 7.47% of mass) compared to a face-sealed mass wall (water content 5.97% to11.36% of mass).

To be noted, moisture content (MC) below 20% dry basis is considered to be a reasonable threshold for hemp decay (Pinkos et al, 2011). Furthermore, the "resting moisture content" (a natural equilibrium level) in hempcrete wall after drying can be expected around 15% and the ideal timing to apply finishing would be when WME (wood moisture equivalent) is less than 23% in surface and 35-40% in below the surface (Stanwix & Sparrow, 2014).

Table 2: Water content of hempcrete and total water content range

Descriptions	Water Content	Assemblies (Base)		Sensitivity Analysis (Assembly 1)			
		Assembly 1	Assembly 2	Sensitivity 1	Sensitivity 2	Sensitivity 3	Sensitivity 4
Hempcrete	kg/m³	23.18- 44.07	13.98-29.00	25.54- 46.93	22.90-43.95	23.38-44.15	24.16-44.41
	%Mass	5.97-11.36	3.60-7.47	6.58-12.09	5.90-11.33	6.02-11.38	6.23-11.45
Total	kg/m²	7.78-17.57	5.13-11.08	8.47-18.47	7.70-17.53	7.84-17.59	8.08-17.67

In addition, no significant impacts on hygrothermal characteristic of hempcrete wall were also noticed during the sensitivity analysis due to some variations in moisture sorption and thermal conductivity, based on published reference values.

CONCLUSIONS

This study concludes that the thermal conductivity of hempcrete is highly influenced by their density. The higher the binder content, the higher the density, leading to a higher thermal conductivity. This relationship follows a near linear pattern. Measurements of dry density and thermal conductivity are ranged from 233 to 388kg/m^3 and 0.074 to 0.103 W/mK respectively. It was also noted that the drying period of hempcrete (in controlled room temperature and RH) was approximately 26 days, where minimum density was stabilized. Finally, based on one-dimensional hygrothermal analysis, the vented rain screen system could be considered as a better option for a hempcrete wall assembly in an Ontario (Canada) Climate.

REFERENCES

Ahlberg, J., Georges, E., and Norlen, M. 2014. The Potential of Hemp Buildings in Different Climates and the Hempcrete Building System. Uppsala University, Sweden.

Arnaud, L., and Amziane, S. 2013. Bio-aggregate-based Building Materials: Applications to Hemp Concretes. ISTE Ltd and John Wiley and Sons, Inc.

Bevan, R., and Woolley, T. 2008. Hemp Lime Construction: A Guide to Building with Hemp Lime Composites. IHS BRE Press.

Collet, F., Chamoin, J., Pretot, S., and Lanos, C. 2013. Comparison of the hygric behavior of three hemp concretes. Energy and Buildings, 62: 294-303.

Dhakal, U., Berardi, U., Gorgolewski, M., and Richman, R. 2017. Hygrothermal performance of hempcrete for Ontario (Canada) buildings. Journal of Cleaner Production, 142: 3655-3664.

Evrard, A. 2008. Transient Hygrothermal Behaviour of Lime-hemp Materials. PHD Thesis. Universite Catholique De Louvain, Belgium.

Hemp Edification. 2015. Retrived from http://hempedification.blogspot.ca/2015/07/hempcrete.html.

Kenter, P. 2015. Championing Hemp: Ontario Builder Promoting Use of Hempcrete. Retrieved from http://dailycommercialnews.com/Projects/News/2015/3/Championing-hemp-Ontario-builder-promoting-use-of-hempcrete-1006745W/.

Pinkos, J., Dick, K., and Whitmore, E., 2011. Load and Moisture Behaviour of Manitoba Hemp for Use in Hempcrete Wall Systems in a Northern Prairie Climate. The Canadian Society for Bioengineering. Paper No. CSBE11-401.

Stanwix, W. and Sparrow, A. 2014. The Hempcrete Book: Designing and Building with Hemp-lime. Green Books, UK.