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Paper No. CSBE11-401

Load and Moisture Behaviour of Manitoba Hemp for use in Hempcrete Wall Systems in a Northern Prairie Climate

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Written for presentation at the
CSBE/SCGAB 2011 Annual Conference
Inn at the Forks, Winnipeg, Manitoba
10-13 July 2011

ABSTRACT The processing of industrial hemp, cannabis sativa, results in three basic constituents – seed, fibre, and hurd. Within the Manitoba context the main focus has been with the grain market and the processing of the seed for oil-based products. When considering the entire plant approximately 60-70% is the predominantly cellulose woody core called the hurd.

A combination of hemp hurd, lime, cement and water in various proportions has been used for centuries in the construction of buildings. In the current vernacular it is often referred to as "hempcrete". Hempcrete is used as an environmental barrier providing resistance to heat transfer and to manage moisture by allowing the wall to breathe. Engineering and architectural designers practicing in the field of non-conventional material applications have clearly indicated a need for design data.

A total of 127 specimens were tested to determine the load-deformation behaviour of hemp hurd with a cementitious binder. Seven binder mixes used with Manitoba-produced hemp hurd were evaluated. Upon completion of the baseline testing one mix design is currently being used in the construction of a test building located on the Alternative Village at the University of Manitoba to evaluate thermal performance in a northern prairie climate. This paper presents the results of the testing.

Keywords: hemp, green building, hemp hurd, hempcrete

INTRODUCTION Due to the increasing awareness of environmental issues such as global warming as well as occupant health of the built environment, alternative building methods that address both of these problems are being explored. The use of hemp lime concrete, more commonly known as hempcrete, for building envelopes is the focus of this paper.

Hemp is an environmentally friendly crop that does not require pesticides or herbicides to grow. It also serves to absorb a significant amount of carbon dioxide during its growth process. Because of its fast growth, ability to grow in both temperate and tropical climates, and strength, hemp has been used for centuries to make a variety of items such as rope, paper, clothing, and sails (Province of Manitoba, 2007). More recently, research has been conducted on hempcrete, a building material utilizing hemp in a binder matrix.

After the removal of the outer bast fibre, the remaining woody core of the hemp stalk, the hurd, has either been used for animal bedding or simply burned. The use of the hemp hurd in hempcrete can now provide extra value to the hemp grower.

The resurgence of hemp in contemporary concrete mixes first occurred in the early 1990's, in France, with the goal being to lighten conventional concrete using hemp chips (Evrard et al. 2006). Since then, much research has been carried out regarding the mechanical properties of hempcrete (Hirst et al. 2010) as well as the different binder mixes that may be used (de Bruijn et al. 2009 and Magniont et al. 2010).

Currently, research on the use of hempcrete is being carried out at the University of Manitoba in Winnipeg, Canada. The focus is to determine the efficacy of hempcrete as a viable insulation material for use in wall systems in the harsh prairie winters. The use of hydraulic lime in the binder matrix appears to be fairly ubiquitous in studies involving hempcrete but because the production of this type of lime is mostly limited to France, the embodied energy required to ship the lime to Canada fails to be a viable "green" alternative. As such, to try and produce a "green" material, locally available ingredients were used for the binder with an emphasis on reducing the amount of Portland cement as well as hemp hurds with a low level of processing to reduce waste material for the processor. A study on the relationship between moisture content and relative humidity has also been carried out (Whitmore, 2011).

MATERIALS AND METHODS

Binder Mix Design The initial phase of the research programme was to determine a useable binder mix design which uses locally available ingredients. To compensate for the absence of hydraulic lime due to its high embodied energy from transportation costs, it was decided that various proportions of hydrated lime, Portland cement, and fly ash would constitute the binder in the test cylinders. In total, seven different mix designs were prepared and are listed in Table 2.

Test Cylinders Approximately 20 test cylinders per mix design were produced to test in compression. By volume, the hurd

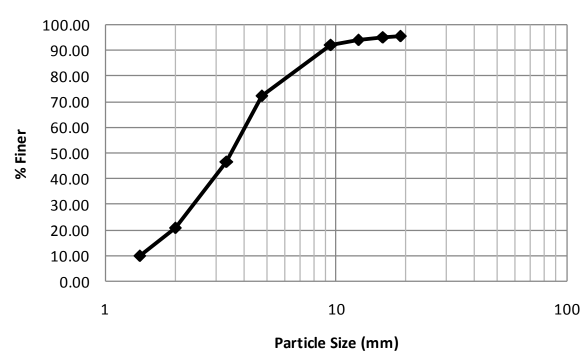
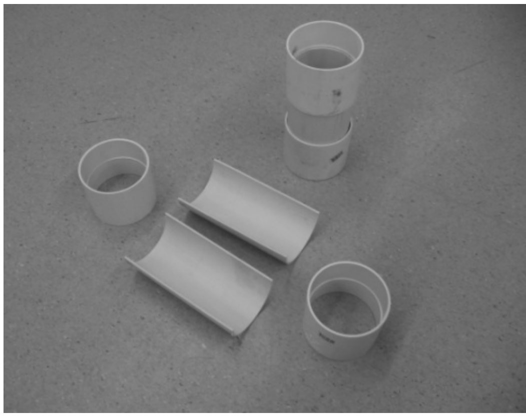


Figure 1. Particle size distribution of hemp hurds



gure 2: Breakaway mold

Figure 3: Curing of test cylinders

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To ensure proper activation of the binder as well as to expedite curing, the cylinders were exposed to 7 days in a high humidity environment (93% Rh, 20°C) followed by 7 days in a higher temperature, low humidity environment (30% Rh, 40°C). Figure 3 shows several sets of cylinders during the curing phase.

Once cured, the cylinders were capped using a sulfur-based compound to allow compressive loads to be distributed uniformly across the entire surface to which the load is applied. The cylinders were tested using an ATS universal testing machine. The compressive loading rate was set at 5 mm/min.

Sorption To gain an understanding of the relationship between the moisture content of hempcrete (LCF1½1) and the relative humidity to which it is exposed, a sorption curve was developed by placing 5.1 cm by 5.1 cm (2 inch by 2 inch) hempcrete cubes in 5 different salt solutions that each produces a known relative humidity within an enclosed space. Embedded within the cubes were Honeywell H1H-4000 relative humidity sensors and each cube was placed in a desiccator containing a different salt solution. Table 1 lists the salt solutions used along with their theoretical and measured relative humidity.

Table 1. Relative humidity of salt solutions

Salt Solution	Relative Humidity (%)	
	Theoretical(1)	Measured(2)
Potassium Dichromate	98.2	100.00
Sodium Chloride	75.5	77.00
Magnesium Nitrate	52.89	50.23
Magnesium Chloride	33	30.27
Potassium Acetate	23.5	26.51

Note: 1. Reference temperature, 25°C
2. Ambient temperature, 23.5°C

The cubes were kept in the desiccators until their internal relative humidity reached equilibrium with that of the desiccator. The cubes were then weighed immediately after removal from the desiccator and placed in a drying oven set to 104°C and weighed again once the dry weight stabilized. The moisture content of the cubes was then calculated by subtracting the dry weight from the wet weight.

RESULTS AND DISCUSSION

Compression Tests The results of the compression tests were analyzed to determine both the compressive strength of the test specimens and the elasticity below the proportional limit, Young's Modulus. Table 2 provides a summary of the findings.

Table 2. Summary of compression test results

Binder Mix (1),(2)	No. Cylinders	Compressive Strength (MPa)			Young's Modulus (MPa)		
		Mean	SD(3)	COV(4)	Mean	SD	COV
LCF111	18	0.166	0.051	0.310	9.505	4.969	0.523
LCF11½	19	0.138	0.016	0.117	6.076	3.027	0.498
LCF110	19	0.200	0.036	0.180	6.581	3.219	0.489
LCF½11	17	0.116	0.014	0.124	8.766	1.949	0.222
LCF011	20	0.198	0.053	0.270	15.677	3.561	0.227
LCF101	17	0.082	0.019	0.235	2.402	0.723	0.301
LCF1½1	17	0.122	0.032	0.263	6.634	1.592	0.240

Note:
1. L, C, and F denote Type S hydrated lime, Type 1 Portland cement, and Class C fly ash respectively
2. 0, ½, and 1 denote the relative proportion of each binder component
3. Sample standard deviation
4. Coefficient of variation based on normal distribution

Young's Modulus was calculated by finding the slop 0.4σ_{max} as is illustrated in Figure 4. This method was modified fr 02. The lower limit was increased to 0.1σ_{max} to avoid data points a of the test.

Figure 5. Hempcrete cylinder after testing

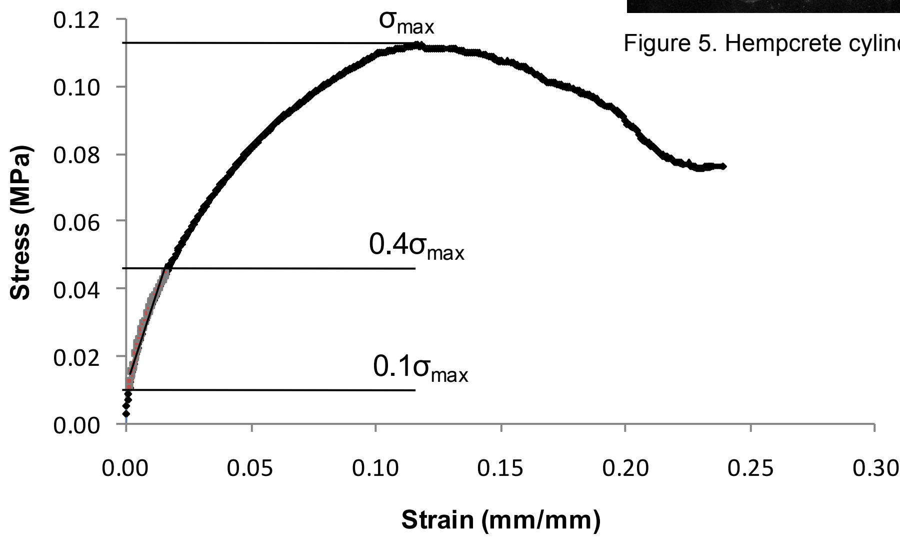
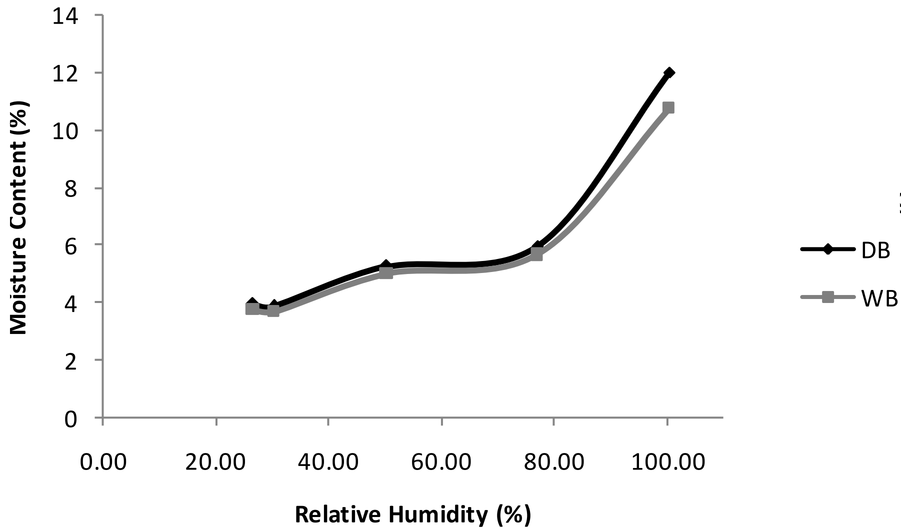


Figure 4. Stress-strain data for specimen 15 from binder mix LCF101

As can be seen from Table 2, the compressive strengths for the test cylinders range from 0.082 to 0.200 MPa and Young's Modulus ranges from 2.402 to 15.677 MPa. The cylinders with the lowest compressive strengths are made with LCF101 which have no cement in the binder mix while the highest strength cylinders are from LCF110.

Going into this phase of the study, it was expected that none of the hempcrete mixes would be particularly strong in compression. However, the effect that each of the binder components had on the overall performance of the hempcrete cylinders was of interest. Figure 5 shows a cylinder after being tested. In choosing the constituents of the binder mix, emphasis was placed on the local availability of the ingredients as well as their expected performance. The combination of hydrated lime with a pozzolan such as fly ash not only was locally available but was also seen as a way to reduce the amount of cement used due to its cementitious properties. Ultimately, binder mix LCF1½1 was chosen based on its reduced cement content and relatively low COV. Ideally, it would be beneficial to determine useable binder mixes for different climates that use locally available materials.

From the sample stress-strain curve in Figure 4 it can be seen that hempcrete can tolerate a relatively large change in geometry while exhibiting reasonable residual strength after maximum load. As an infill material for wall systems, this may be of benefit in terms of racking resistance and energy absorption.



gure 6.

gure 6. Sorption curve, wet and dry basis

Because the hurd is predominantly cellulose, ranges in moisture content outlining the onset of mold growth for wood may be considered until further research is conducted. As can be seen from the sorption curve, the moisture content of the hempcrete at 98% relative humidity is not much greater than 12%. Given that the hurd is essentially a cellulosic material, the authors believe that a moisture content below 20% dry basis is considered to be a reasonable threshold for decay (SWST, 1982).

CONCLUSION A total of 127 hempcrete cylinders using 7 binder mix designs along with Manitoba-grown hemp hurds were tested in compression. The binder mixes used varied in their proportions of Type S hydrated lime, Class C fly ash, and Type 1 Portland cement. The tests were conducted to see how the different components of the binder affect the compressive strength of the hempcrete as well as the elasticity. The results show that the compressive strength of hempcrete is far below that of conventional concrete. However, the low values for Young's Modulus show that hempcrete can withstand significant geometric changes under residual stress. Based primarily on the lower cement content, a binder mix composed of 1 part hydrated lime to ½ part Portland cement to 1 part fly ash was chosen for the use in a test building, that is currently being constructed, where the thermal performance in a northern prairie climate will be evaluated.

A test was performed on 5 cm by 5 cm (2 inch by 2 inch) hempcrete cubes in which the moisture content of the cubes was measured in relation to its ambient relative humidity using saturated salt solutions. It was found that at 98% relative humidity, the dry basis moisture content was just above 12%.

These tests show that hempcrete is not suitable for load-bearing applications in its current form; however, as infill in a wall system, its ability to handle moisture looks promising.

ONGOING RESEARCH Thus far, the research conducted on hempcrete by the authors has only dealt with the load and moisture handling abilities of small-scale samples where hydrated lime, Portland cement, and fly ash have been used in the binder mix designs. The following research activities are currently underway at the Alternative Village:

- The construction of a panelized test building in the Alternative Village at the University of Manitoba in which temperature and relative humidity will be monitored.
- Racking test of a full-size wall panel
- Additional measurements of moisture content in hempcrete

ACKNOWLEDGEMENTS The authors would like to express their appreciation to Emerson Hemp Distribution Company for their support of this research as well as the technicians in Biosystems Engineering and student Shawn Wiebe for his assistance.

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