7th International Conference on Engineering Mechanics and Materials 2019
CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montréal)
June 12 - 15, 2019

IMPACT OF CEMENTITIOUS MATERIAL TYPE AND COMPLEX MINERALIZER ON THE COMPRESSIVE STRENGTH OF HEMPCRETE

Liu, Michelle C.[1,2], Van Niejenhuis, Colin[1,3], Aurilio, Roberto M.[1,4], Baaj, Hassan[1,5]
[1] Department of Civil and Environmental Engineering, University of Waterloo, Canada
[2] BASc, EIT, Candidate for MASc; michelle.liu@uwaterloo.ca
[3] MASc, EIT, Candidate for PhD; cvanniejenhuis@uwaterloo.ca
[4] BASc, EIT, Candidate for MASc; roberto.aurilio@uwaterloo.ca
[5] P.Eng., PhD; hassan.baaj@uwaterloo.ca

Abstract: Hemp hurds possess numerous desirable properties as a building material, including its low density, moderate tensile strength, renewable source, and ability to sequester carbon throughout its cultivation and service life. Previous experiments explored the complete substitution of coarse aggregates with hemp hurds in general-use Portland cement concrete mixes, but extremely low compressive strengths were recorded. In this paper, the substitution of coarse aggregates with hemp hurds is paired with the use of a complex mineralizer and various combinations of general-use Portland cement, general-use Portland-limestone cement, and blast furnace slag. Results indicated that compressive strength values after 28 days of curing are three times higher with the addition of complex mineralizer than without. Of the mixes with complex mineralizer, the combination of general-use Portland cement and blast furnace slag yielded the highest strength at 28 days. Density for the specimen with Portland cement and complex mineralizer was also calculated and compared to a typical Portland cement concrete specimen with coarse aggregates. From this, it was found that the substitution of all coarse aggregates with hemp hurds reduces the density of the concrete by up to 30%.

Keywords: Cannabis, Construction, Building Materials, Biocomposites, Sustainability

1 INTRODUCTION

Hemp is an organic material known for its industrial applications in Europe and Asia but has historically been stigmatized in North America due to its appearance. Hemp is a biotype of the species *Cannabis sativa* (*C. sativa*), which includes another biotype commonly known as marijuana. Biotypes are variations of a species that share the same genotype but have adapted or been modified to exhibit differentiable physiological characteristics, or phenotypes. In the case of *C. sativa*, the level of Δ^9-tetrahydrocannabinol (THC) present is the key difference between hemp and marijuana. THC is responsible for the intoxicating effects of marijuana and is known to have such effects when present at a level of 1% or greater. Technically, all *C. sativa* plants that contain less than 1% THC can be classified as hemp, but most countries in the world follow the threshold of 0.2% established by the European Union (Cherney and Small, 2016). Canada and the United States have retained the threshold of 0.3% THC first determined in 1976 to distinguish between hemp and marijuana (Small and Cronquist, 1976). However, with the recent legalization of marijuana across Canada, the interest in hemp is expected to become more widespread in the building industry upon overcoming its supply barrier.

Hemp is one of the fastest growing plants on the planet (Deitch, 2003) and can reach a height of 4 metres in 4 months with minimal fertilization and irrigation (Gross and Walker, 2014). Hemp hurds are also much more resistant to biological decay compared to other biomass materials, like straw. Hemp hurds are the lignin-rich inner portion of the stalk, the outer layer of which is surrounded by phloem. Phloem in hemp is commonly extracted as bast fibre for textile through a process known as decortication, of which hemp hurds are a byproduct (Bouloc et al., 2013).

With the growing focus on sustainability, hemp hurds are not only beneficial due to its recycled nature, but also because of the ability of its source plant to sequester CO_2 throughout cultivation. In a life cycle analysis, Pervaiz and Sain found in 2003 that hemp is estimated to sequester around 0.0607 kg of CO_2 per m^2 of cultivation each year ($kg/m^2/year$). A 2012 study by Shea et al. also indicated that for every kg of hemp hurds, 2.1 kg of CO_2 is sequestered from the atmosphere by the source plant. The same study found that 300-mm hempcrete walls of 1:2 hurd-binder proportion sequestered around 75.5 kg of CO_2 per m^2 of wall; and 35.5 kg of CO_2 per m^2 of wall when the CO_2 emitted during manufacturing, transportation and construction is considered.

Dhakal et al. investigated the hygrothermal performance of Canadian-grown hemp in structural applications. Unlike the majority of hygrothermal studies which are based in Europe, this study is particularly relevant to construction applications in Canada and the United States. It was observed that the thermal conductivity (*k*-value) is highly influenced by the density of the hempcrete; the higher the binder content of a hempcrete wall, the higher its thermal conductivity. It was also found that a wall using a rainscreen system with a total thickness of 355 mm (constructed of wood cladding, an appropriate air gap with continuous air changes of 8 per hour, typar house wrap, 300 mm hempcrete, and lime plaster) would be capable of meeting the thermal performance requirements for Ontario (Ontario Building Code, 2012). At the University of Manitoba, a similar study was conducted on a test building with total surface area of 24 m^2 and built using 300 mm thick pre-fabricated hempcrete panels. The hemp building had stable and consistent temperature profile through the wall cross-section as well as good moisture and humidity management in temperatures ranging from -35 °C to +32 °C (Dick and Pinkos, 2014).

Hemp concrete, or hempcrete, is generally known to have less than 2 MPa of compressive strength (Bütschi, 2004; Eires et al., 2005; Elfordy et al., 2008). Combined with its Young's modulus reported at approximately 20 MPa (Arnaud & Gourlay, 2012), hempcrete in this form is not expected to be useful in load bearing capacities but may be suitable infill material for wall systems due to its hygrothermal properties (Pinkos et al, 2011). However, Pantawee et al. explored the mineralization of Thai hemp hurds with aluminum sulfate ($Al_2(SO_4)_3$) and calcium hydroxide ($Ca(OH)_2$) prior to utilizing the hurds as a coarse aggregate replacement. Compressive strengths of up to 15 MPa were found after 28 days, with the $Al_2(SO_4)_3$ to $Ca(OH)_2$ ratio of 1:2 yielding the highest strength (Pantawee et al., 2017). The same mineralizers, $Al_2(SO_4)_3$ and $Ca(OH)_2$ were used in a 2015 study by Balciunas et al., which yielded the maximum compressive strength of 8.03 MPa after 28 days when mineralizers were used in the amount of 54% by mass of hemp hurds.

2 SCOPE AND OBJECTIVES

This study consisted of the compressive testing of four hempcrete mix designs at 7, 14, 21 and 28 days. The objectives were to quantify the percent increase in compressive strength of a mix with the complex mineralizer compared to one without, and to determine the cementitious material combination that yields the highest compressive strength.

3 MATERIALS

3.1 Hemp

Approximately 10 kg of hemp sample provided by Ontario Hemp Materials were utilized, all of which was cultivated in Ontario. The sample was a labelled to be a blend of hemp hurds and fibre, although visual inspection revealed that hurds are the dominant component. Benfratello et al. (2013) found that hemp hurds used in hempcrete should be chopped to between 2 and 8 mm in size in order to create a workable and homogeneous material. The gradation of the sample found using sieve analysis and can be seen in Table 1 and Figure 1.

Of the many chemical components in lignin-rich plants like hemp, sugar is the main inhibitor of cement hydration (Pehanich et al., 2004). Sugar in small concentrations is known to delay the setting of concrete and can prevent the hardening process all together in large concentrations. This likely explains in part the low strength associated with traditional hempcrete. As such, subjecting hemp hurds to chemical treatment prior to mixing should be considered if higher strengths were desired (Balciunas et al., 2015).

Table 1: Hemp hurd gradation analysis.

Individual size fraction	Percent Retained (%)
9.5 - 4.75 mm (no. 4)	44.6
4.75 - 2.36 mm (no. 8)	45.7
2.36 mm - Pan	9.7
Total	100.0

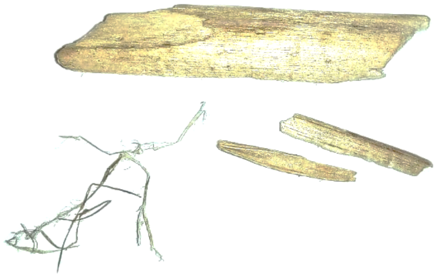

Figure 1: Hemp hurds and fibres.

3.2 Complex mineralizer

As done by Balciunas et al. (2015) and Pantawee et al. (2017), this study used $Al_2(SO_4)_3$ as the complex mineralizer. $Al_2(SO_4)_3$ impedes the release of sugar from organic aggregates, thus reducing the impact of hemp hurds on setting time. $Al_2(SO_4)_3$ is most commonly available in hydrate form, and technical grade $Al_2(SO_4)_3 \cdot 14H_2O$ was used in this study. Mineralizing organic aggregates with $Al_2(SO_4)_3$ has also been known to improve the ability of cement to coat the aggregates, thus improving adhesion (Balciunas et al., 2015).

3.3 Cementitious materials

All specimens in this report were prepared using general use (GU) Portland cement, Supplementary cementitious materials include limestone filler and blast-furnace slag (BFS). The limestone filler was preblended with the general use cement to create an 80:20 general use cement + lime admixture (referred to as GUL). Limestone fillers, composed of calcium carbonate ($CaCO_3$), are an alkaline material with the ability to neutralize strong bases. In previous literature, strong alkaline materials such as hydrated lime were used to neutralize the complex mineralizing agent (Pantawee et al., 2017). In many jurisdictions in Europe and the United States, limestone fillers are also used to replace the cement clinker in the concrete mix; limestone additions in concrete help reduce the carbon dioxide emissions and decrease the cost of the concrete (Bentz et al., 2009). Typically, limestone additions increase the density of concrete by completing the fine fraction and improving cement packing without the need to increase the water content leading to stronger, denser concrete mixes. Limestone can also improve the short-term strength gaining ability of concretes by impeding the formation of competing and less-effective hydration productions in the cement (Menéndez et al., 2003).

Blast-furnace slag is an environmentally-friendly use of steel production waste streams. Ground granulated blast furnace slag (BFS), when blended with Portland cement and water, forms several beneficial hydration products that improve the late-stage strength gaining ability of concrete. However, the initial low rate of hydration of slag-containing mixes could lead to poor early strength. Concrete mixes containing BFS have improved resistance to sulphate attack caused by limestone aggregates. Ternary mixtures of limestone and BFS have been proven to overcome the drawbacks of using limestone and slag separately. In the proper proportions, limestone-BFS-Portland cement mixes have good early and late stage strength gaining capabilities. These ternary mixtures make efficient use of natural resources or waste products streams while reducing energy and cost of the concrete production (Menéndez et al., 2003).

3.4 Superplasticizer

MasterGlenium 7700 was the superplasticizer used in this study. It is a high-range polycarboxylate admixture that is intended to improve the consistency of concrete mixes. It alters concrete mixes in accordance to ASTM C494 requirements for Type A, water-reducing, and Type F, high-range water-reducing, admixtures.

4 METHODOLOGY

4.1 Mix Design

Four mix designs were created for this study. A mix with no $Al_2(SO_4)_3$ was designated as the control sample. The other three mixes contained $Al_2(SO_4)_3$ and various combinations of GU, GUL, and BFS. Control and mix 2 can be compared to determine the effect of $Al_2(SO_4)_3$. Mix 1 and Mix 2 can be compared to determine the effect of BFS. Mix 2 and Mix 3 can be compared to determine the effect of substituting GU with GUL, although the BFS content was slightly lower in Mix 3. These designs are summarized below in Table 2.

Table 2: Hempcrete mix design.

	Hemp hurds (kg)	Fines (kg)	Cementitious materials (kg)			Water (kg)	Super-plasticizer (mL)	Mineralizing solution (kg)	
			GU	GUL	BFS			$Al_2(SO_4)_3$	Water
Control	2.59	32.39	12.15		4.05	7.77	0	-	4.83
Mix 1	2.59	32.39	16.20			7.77	100	0.466	4.83
Mix 2	2.59	32.39	12.15		4.05	7.77	100	0.466	4.83
Mix 3	2.59	32.39		12.96	3.24	7.77	100	0.466	4.83

The water-cementitious material (w/c) ratio was 0.48 by mass; the hemp-cement (h/c) ratio was 0.16 by mass; and the cement-fines (c/f) ratio was 2:1 by mass. 100 mL of superplasticizer was added to each mix regardless of mass, as well as 0.466 kg of $Al_2(SO_4)_3$.

4.2 Specimen Preparation

Air-dried hemp hurds were mixed with the mineralizing solution for 3 minutes using an electric hand mixer and were left undisturbed for 15 minutes to allow saturation. In the revolving concrete pan mixer, cementitious materials (various combinations of GU, GUL and BFS as per Table 2) were combined with the saturated hemp hurds and mixed for 3 minutes, followed by the addition of water, fine aggregates, and superplasticizers. With all components added, the concrete is mixed in the pan for approximately 3 more minutes before being transferred to a barrel where it was hand-mixed using trowels (Pantawee et al., 2017).

Before casting, each mix was tested for workability using the slump test (ASTM C143). Specimens were cast into 100 x 200 mm cylinder molds in accordance with ASTM C192. Capped cylinders were cured upright at room temperature (approximately 23°C) for 7, 14, 21 and 28 days before being demolded for compressive testing.

4.3 Specimen Testing

Specimens were demolded at 7, 14, 21 and 28 days respectively for compressive strength testing. Demolded specimens were ground using a Marui Hi-kenma three-specimen end-grinder for approximately 2 to 3 minutes. Specimens that could not be ground due to poor fibre adhesion were tested with unbound - rubber caps on both ends of the cylinder. Cylinders were placed into an MTS C64-605E loading frame and loaded in uniaxial compression (stress-controlled) at a loading rate of 0.3 MPa/sec. The loading behaviour and peak load were determined in accordance with ASTM C39. The compressive strength of each specimen is calculated as shown in Equation 1.

[1] $$f_{cm} = 4000 \cdot \frac{P_{max}}{\pi D^2}$$

In Equation 1, f_{cm} is the compressive strength of the specimen, in MPa, P_{max} is the peak load experienced during testing, in kN; and D is the average diameter of the cylinder, in mm. The modified specimen density was also calculated using the specimen dimensions after the 28-day curing time. The specimen density is calculated as shown in Equation 2.

[2] $$\rho_{28} = 4x10^9 \cdot \frac{W}{L\pi D^2}$$

In Equation 2, ρ_{28} is the specimen density after 28-day curing time, in kg/m^3; W is the specimen weight after 28-day curing time, in kg; L is the average length of the specimen, in mm; and D is the average diameter of the specimen, in mm. The specimen density is rounded to the nearest 10 kg/m^3 in accordance with ASTM C39, Section 9.3.

5 RESULTS AND DISCUSSIONS

5.1 Fibre Distribution and Density

Upon demolding the control specimens, it was observed that these unmodified samples were much softer with the appearance of a moist, clay-like material. Consequently, the lapping motion of the grinder had the tendency to pull hemp from the cylinder surface due to the poor hemp hurd adhesion in the control specimens. Specimens containing the mineralizing agent were harder with improved hemp-cement adhesion; cylinders containing these mixes could be ground successfully with little to no fibre pull-out. Through the grinding process it was revealed that the bottom of the cylinders had a lower concentration of hemp small fibres compared to the top of cylinders, as seen in Figure 2. This observation could be the result of low-density hemp hurds floating to the top before setting in the vertically curing concrete molds.

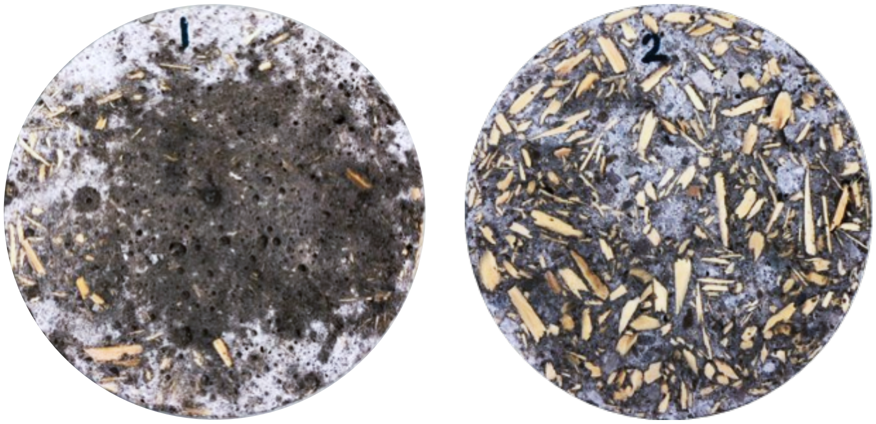

Figure 2: Fibre distribution of the bottom (left) and top (right) surfaces of ground specimen cylinders.

The 28-day bulk density of all modified specimen types ranged from 1680 to 1780 kg/m^3. Mix 1 and 3 had similar densities at 1680 and 1690 kg/m^3, respectively. Mix 2 had the highest density corresponding to 1780 kg/m^3. All modified specimens can be considered structural light-weight concretes (SLWC) according to ASTM C39 as all modified specimens exhibit a 28-day bulk density in the range of 1600 – 1900 kg/m^3. Generic concretes using stone aggregates typically have bulk densities corresponding to 2400 kg/m^3; hemp concretes made using the mix design found in Table 2 could represent a 26-30% reduction in the density (Dorf, 2005). As previously stated, the thermal conductivity of the concrete decreases as its density decreases. In other words, lower thermal conductivity values correspond to improved thermal insulation properties. In literature, sprayed hempcretes with high hemp-to-binder ratios and corresponding densities lower than 700 kg/m^3 have reported dry k-values ranging from 0.06 to 0.138 W/m·K. Typical SLWCs have reported k-values ranging from 0.8-1.05 W/m·K. This range is much lower than conventional concretes, which can have thermal conductivity values as high as 3.3 W/m·K (Asadi et al, 2018; Dhakal et al, 2016). Mineralized hempcretes may have similar thermal conductivity values as the specimens in this study can be classified as SLWCs. Further investigation of the thermal conductivity of mineralized hempcretes can help determine whether they are viable alternatives for structures in remote and/or Northern regions.

5.2 Compressive Strength

Figure 3 presents the average 7, 14, 21 and 28 compressive strength of the four specimen types. Control specimens were tested using an unbonded cap on the top surface of the cylinder as seen in Figure 4a. The control specimens had the lowest compressive strength after each curing period. The values for the control specimen were 0.4, 0.9, 1.5 and 2.7 for the 7, 14, 21 and 28-day compressive strength tests, respectively. The control specimens had a very modest increase in strength over the 28-day period, but their overall lower strength can be attributed to higher rates of water absorption in the untreated hemp. Control specimens exhibited moderate ductility and did not fail through brittle fracture in any of the typical concrete fracture patterns presented in ASTM C39.

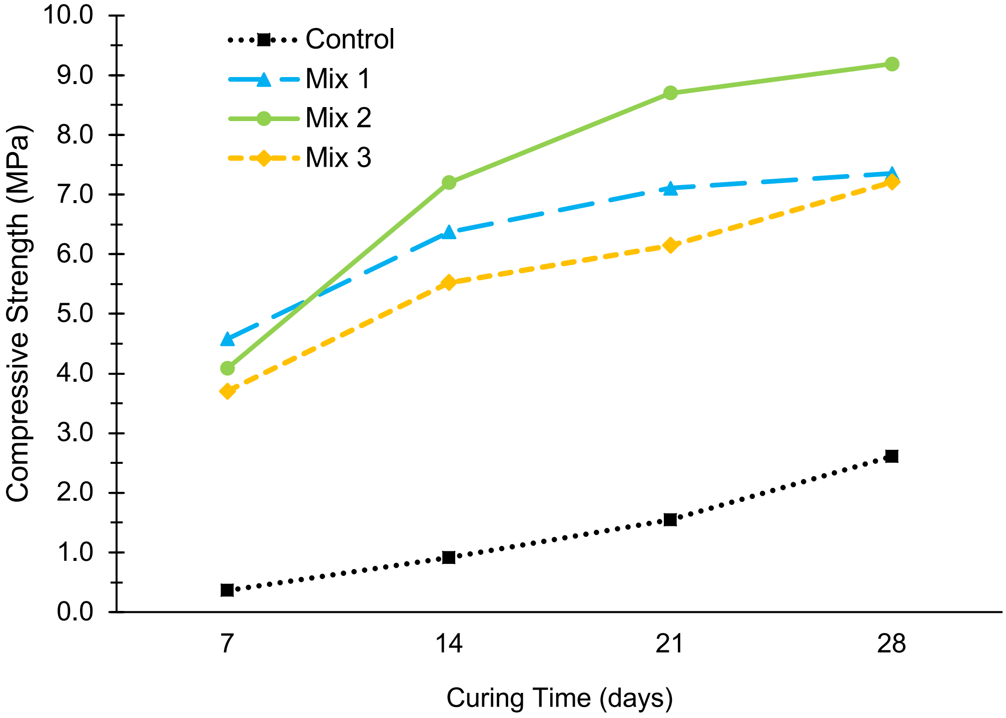

Figure 3: Compressive strength of concrete specimens at 7, 14, 21 and 28-day curing times.

Specimens containing the mineralizing agent demonstrate a much higher 7-day compressive strength compared to the control; the 7-day values for Mix 1, Mix 2 and Mix 3 were 4.6, 4.1 and 3.7 MPa, respectively. At 14 days curing time, mixes containing the mineralizing agent ranged from 5.5 – 7.2 MPa; Mix 2 had the highest compressive strength value with 7.2 MPa. At 21 days, the compressive strength in mixes containing the mineralizing agent ranged from 6.1 – 8.7 MPa. Finally, at 28 days, the mix compressive strength values ranged from 7.2-9.4 MPa. Mix 2 had the highest strength value after 14 days and this trend continued through to the 28-day compressive strength test. These strength values demonstrate that the mineralization of hemp aggregates could produce hempcretes suitable for structural applications in small buildings or as a base/subbase material in pavement construction.

The modified specimens had significantly higher compressive strength values compared to the control specimen due to the increased hygroscopic properties of mineralizing agent treated hemp hurds. As seen in Figure 4b, these samples exhibited the more-typical brittle concrete failure under loading conditions. Even after fracturing, the specimens will deform until there is complete fibre pull-out between fracture surfaces. From visual inspection of the fractured surfaces, it was observed that most hemp hurds appeared to remain undamaged in the fractured concrete with very little cementitious residue on the outer surface of the fibre as seen in Figure 4c. It was also observed that hurds appear to have two types of failure. The first failure type appears to be hurds that have broken into two or more pieces along the hurd length (represented as fractured surfaces with small hemp fibrils) and the second failure type appears to be caused by the separation of the hurds from the binder (i.e. hurd-matrix interfacial bond failure). Fibres that fail at the hemp-binder interface are primarily oriented in the direction of the concrete fracture plane. As a result of the improvement in adhesion of the hurds increases, the second failure type seems to be less prevalent. The improved adhesion leads to increased compressive strength as well as an improvement of the after-fracture properties of the concretes. Hurds extend the life of the concrete past the initial fracture in two ways: (1) hurds that are anchored in both fracture surfaces can span across cracks to as a load transfer device, and (2) fibres randomly distributed in the mix can mitigate existing crack propagation in the binder.

From Figure 3, it appears that all mixes containing blast-furnace slag have an increasing trend at the 28-day. Mix 1, the only concrete not containing slag, has the lowest relative strength increase between the 21 and 28-day testing intervals. Beyond the 28-day curing time Mix 1 is not expected to have any appreciable strength gain from the formation of cement hydration products. In general, mixes containing slag have much greater strength increases near the end of the 28-day period; this could be attributed to the late-stage (after 21-day) strengthening caused by the formation of hydration products in the Portland cement-slag-water mixture. Slag-based hydration products have similar strengthening mechanisms compared to calcium silicate hydrate (C-S-H) products found in typical Portland cement-water mixes. Unlike Portland cement C-S-H products, slag-based hydration products can considerably improve the compressive strength of the concrete past 90-day curing periods (Menéndez et al., 2003).

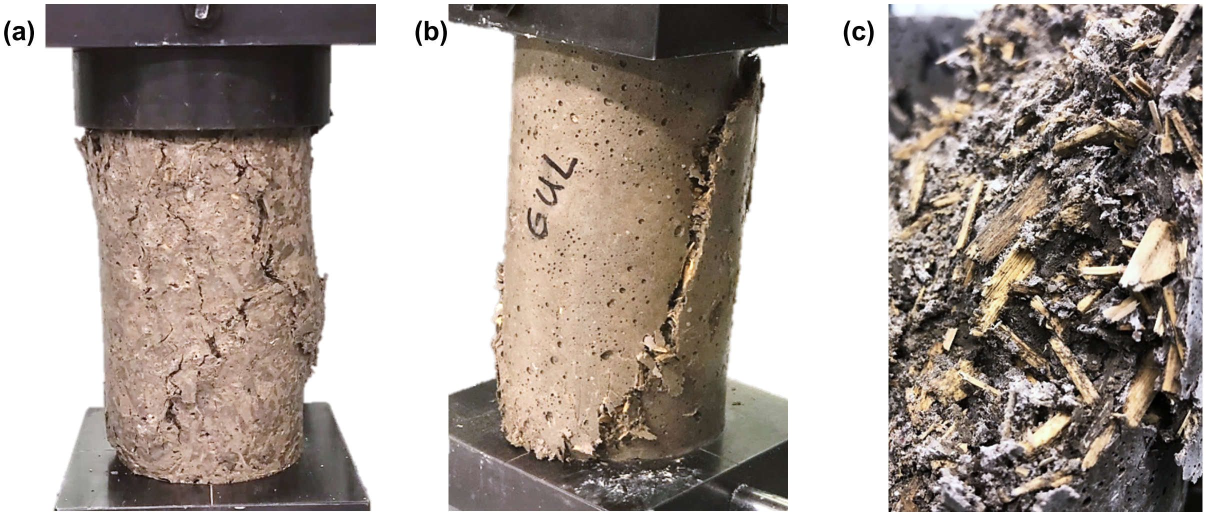

Figure 4: (a) Moderate ductile failure of control specimens, (b) representative brittle diagonal fracture (ASTM C39 Type 4) of modified specimens, and (c) representative macro photo of hemp failure at concrete fracture surfaces.

The only limestone treated mix, Mix 3, has the lowest 7- 21 day compressive strength values compared to other modified mixes. This result is contrary to the traditional understanding of the effect of limestone fillers on early concrete strength. It is expected that limestone-treated concrete mixes generally have higher early strength compared to untreated concrete as limestone increases the number of nucleation sites for the formation of strength increasing hydration products. During the initial curing (7-21 days), if the aluminum sulphate is not completely neutralized by the limestone, unmineralized hemp hurds will have high sugar content leading to higher water absorption and decreased hydration products in the binder (Balciunas et al., 2015). Similarly, if the w/c ratio decreases below 0.42, the limestone filler will not have any increasing effect on the early concrete strength (Bentz et al., 2009). As an inert filler, the limestone would marginally improve the density of the mix and therefore, the compressive strength (as stated in section 3.3), but it could also decrease the short-term compressive strength of the concrete because: (1) fewer C-S-H hydration products are formed in the hemp concrete as a result of the lower Portland cement content and

(2) the limestone fraction in the binder has a lower compressive strength compared to Portland cement (Balciunas et al., 2015). This effect could be compounded by the effects of blast-furnace slag which is known to reduce the early strength of concrete mixtures. This effect of slag on concrete can be observed through the lower 7-day compressive strength of Mix 2 and 3 compared to Mix 1 which does not contain slag.

6 CONCLUSION AND RECOMMENDATIONS

An analysis of the hemp concrete mixed with mineralizing agents and supplementary cementitious materials was performed. The mineralizing agent, aluminum sulfate, effectively increased the compressive strength of hemp concretes by decreasing the water absorption and improved hurd adhesion with the binder. Slag-containing hemp concretes demonstrated improved strength in the long-term (between 21-28 days) due to the formation of strong hydration products. Concretes containing slag (BFS) demonstrated a trend of increasing strength past the 28-day curing period while mixes not containing slag appear to approach their maximum compressive strength at 28 days. GUL may be less effective at providing early strength in hemp concretes as it acts as an inert filler. Limestone does not seem to hinder the long-term strength-gaining ability of slag while improving specimen density. Hemp hurd/fibres also improve the after-fracture capabilities of concrete by distributing the load and reduce crack propagation within the concrete binder.

Findings in this study indicated that the use of mineralized hemp, a byproduct of bast fibre manufacturing, produces hempcrete that is three times stronger than using hemp and GU alone. Mineralized hemp concretes can be used in combination with slag, also a recycled material, to improve late-stage strength-gaining. These findings present a two-fold advantage in terms of sustainability (hemp and slag) and are worthy of further investigation for structural applications or as a base/subbase material in pavements.

Recommendations include using higher slag content to improve late-stage strength-gaining potential of hemp concretes and avoiding limestone fillers when using highly water absorbent aggregates such as hemp. With aluminum sulfate being acidic in nature, it may be worthwhile to investigate the use of calcium hydroxide as a secondary complex mineralizer, as suggested in various cited studies, to neutralize the hydration reaction and improve workability of mixes. The investigation of mineralizers that are more cost-effective than aluminum sulfate is also recommended.

7 ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of Erinne Vargas to a related course project that led to the development of this paper. The authors would also like to thank technicians Richard Morrison and Douglas Hirst for their continued guidance in the structural laboratories, as well as Eskedil Melese, Emily Zhang, Lamar Bashbishi, Kyle Gawtrey, and Shenglin Wang for their assistance with various tasks throughout the study. Hemp hurds were courteously provided by Ontario Hemp Materials.

8 REFERENCES

Arnaud, L., & Gourlay, E. (2012). Experimental study of parameters influencing mechanical properties of hemp concretes. Construction and Building Materials, 28(1), 50-56. doi:10.1016/j.conbuildmat.2011.07.052

Asadi, I., Shafigh, P., Fitri Bin Abu Hassan, Z., Binti Mahyuddin, N. (2018). Thermal conductivity of concrete – A review, Journal of Building Engineering, (20) 81-93, ISSN 2352-7102, doi:10.1016/j.jobe.2018.07.002.

Balciunas, G., Pundienė, I., Lekūnaitė-Lukošiūnė, L., Vėjelis, S., & Korjakins, A. (2015). Impact of hemp shives aggregate mineralization on physical–mechanical properties and structure of composite with cementitious binding material. Industrial Crops and Products, 77, 724-734. doi:10.1016/j.indcrop.2015.09.011

Benfratello, S., Capitano, C., Peri, G., Rizzo, G., Scaccianoce, G., & Sorrentino, G. (2013). Thermal and structural properties of a hemp–lime biocomposite. Construction and Building Materials, 48, 745-754. 10.1016/j.conbuildmat.2013.07.096 Retrieved from https://www.sciencedirect.com/science/article/pii/S0950061813007198

Bentz, D. P., Irassar, E. F., Bucher, B. E., and Weiss, W. J. (2009). Limestone Fillers to Conserve Cement in Low w/cm Concretes: An Analysis Based on Powers' Model. Concrete international, 3(November), 41–46.

Bouloc, P., Allegret, S., Arnaud, L., West, D. P., & Cousquer, G. (2013). Hemp industrial production and uses. Wallingford: CABI.

Butschi, P. (2004). Utilisation du chanvre pour la préfabrication d'éléments de construction. ProQuest Dissertations Publishing). Retrieved from https://search.proquest.com/docview/305036578

Dick, K.J., Pinkos, J. (2014). Thermal, moisture and energy performance of a hempcrete test structure in the northern prairie climate of Manitoba, Canada. Key Engineering Materials, (600), 475-482

Dhakal, U., Berardi, U., Gorgolewski, M., & Richman, R. (2017). Hygrothermal performance of hempcrete for Ontario (Canada) buildings. Journal of Cleaner Production, 142, 3655-3664. 10.1016/j.jclepro.2016.10.102 Retrieved from https://www.sciencedirect.com/science/article/pii/S095965261631722X

Deitch, R. (2003). Hemp: American history revisited: The plant with a divided history. New York: Algora Pub. doi:ISBN 978-0-87586-226-2.

Dorf, R. C. (2005). The Engineering Handbook. Boca Raton: CRC Press. doi: 978-1-31522-033-8

Eires R., Nunes P., Fangueiro R., Jalali S., Cameos A. (2006). (2006). New eco-friendly hybrid composite materials for civil construction. Paper presented at the European Conference on Composite Materials,

Elfordy, S., Lucas, F., Tancret, F., Scudeller, Y., & Goudet, L. (2008). Mechanical and thermal properties of lime and hemp concrete ("hempcrete") manufactured by a projection process. Construction and Building Materials, 22(10), 2116-2123. 10.1016/j.conbuildmat.2007.07.016 Retrieved from https://www.sciencedirect.com/science/article/pii/S0950061807001973

Gross, C., & Walker, P. (2014). Racking performance of timber studwork and hemp-lime walling. Construction and Building Materials, 66, 429-435. 10.1016/j.conbuildmat.2014.05.054 Retrieved from https://www.sciencedirect.com/science/article/pii/S0950061814005388

Menéndez, G., Bonavetti, V., and Irassar, E. F. (2003). "Strength development of ternary blended cement with limestone filler and blast-furnace slag." Cement and Concrete Composites, 25(1), 61–67.

Ontario Building Code (2012).

Pantawee, S., Sinsiri, T., Jaturapitakkul, C., & Chindaprasirt, P. (2017). Utilization of hemp concrete using hemp shiv as coarse aggregate with aluminium sulfate [Al2(SO4)3] and hydrated lime [Ca(OH)2] treatment. Construction and Building Materials, 156, 435-442. doi:10.1016/j.conbuildmat.2017.08.181.

Pehanich, J.L., Blankenhorn, P.R., Silsbee, M.R. (2004). Wood fibre surface treatment level effects on selected mechanical properties of wood fibre-cement composites, Cem. Concr. Res. (34), 59–65.

Pinkos, J., Dick, K.J., 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 (CSBE/SCGAB) 2011 Annual Conference, Winnipeg, Manitoba 10-13 July 2011

Shea, A., Lawrence, M., & Walker, P. (2012). Hygrothermal performance of an experimental hemp–lime building. Construction and Building Materials, (36), 270-275. Retrieved from http://www.sciencedirect.com/science/journal/09500618.