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Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

PHYSICAL AND MECHANICAL PROPERTIES OF FLAX LIME CONCRETE

Garikapati, Krishna Priyanka[1], and Sadeghian, Pedram [1,2]
[1] Dalhousie University, Canada
[2] Pedram.Sadeghian@dal.ca

Abstract: Due to increase in production of construction materials, the emission of carbon dioxide levels and the requirement for production materials with a less environmental footprint is gaining more attention. One of the solutions for the problem is to replace high carbon dioxide emitting construction materials with plant-based materials, for example flax shives. Flax shives are obtained from the inner part of flax stem and produced as by-products of flax fiber production, from textile industry. So, as a solution to decrease amount of environmental footprint this paper involves the study of a special kind of concrete (without stone aggregates) made of flax shives and a lime binder. This product is called flax lime concrete hereafter. The study was mainly based on physical and mechanical properties of flax lime concrete like density, load capacity, failure mode, and load-deflection behavior. To study these properties three flax lime concrete beam specimens were prepared with a rectangular cross-section (152 mm x 51 mm) and length of 610 mm. The mix proportions were kept constant for all three specimens to check how loading and displacement were being varied for all three specimens of same mix proportions. A layer of jute, fiber-based fabric mesh was placed at the center of the specimens as reinforcement. Finally, specimens were tested under three-point loading to study the physical and mechanical properties of specimens. The flax lime concrete used in this study shows an average density of 559 kg/m^3 and flexural strength of 1.0 MPa. This paper is a part of an in-progress project focused on the application of flax lime concrete for prefabricated blocks for filling the cavity of building walls as an insulation.

1 INTRODUCTION

The manufacture of concrete raw materials and other building materials requires large amount of energy for their production also produces high levels of green house gases especially carbon dioxide (CO_2). A remedy for the problem is using plant-based materials like flax and hemp, which can absorb CO_2 as they grow also helps to replace non-renewable fibers such as fiberglass. Flax and hemp materials have a good flexural strength, so they can be used as reinforcement. These natural fibers are obtained from stalk (stem) of plants as short and long woody by-products. In this study short woody by-products known as shives and hurds were used, whereas long natural fibers have been used in the form of fiber-reinforced polymer composites (Hristozov et al. 2016, Sadeghian et al. 2018, and Betts et al. 2018). The main aim of this research is to study how short flax shives mixed with a lime-based binder work as a construction material, mainly as an insulation and/or filler material in the cavity of walls in buildings. The product can be cast-in-place for the wall cavities or it can be prefabricated as blocks or panels and then be placed in the wall cavities. This research mainly targets the prefabricated panels made of flax shives.

There are no or limited studies on flax shives, but there are a good number of studies on hemp shives. So, hemp lime concrete studies are taken as reference. Ip and Miller (2012) had investigated the levels of emission of greenhouse gases throughout the life cycle of a hemp-lime concrete wall (1.0 x 1.0 x 0.3 m^3). The mix proportions of binder used for hemp lime concrete wall, 75% of hydrated lime,15% of hydraulic lime, and 10% of pozzolans. The amount of CO_2 emission was 36.08 kg per wall from the time of construction till the end of the lifespan of the wall with the volume of 0.3 m^3. Nguyen et al. (2009) studied hemp lime concrete (a mixture of hemp shives plus a lime-based binder) also known as hempcrete. The hemp lime concrete was made of a binder containing 75% non-hydraulic lime of total volume of binder, 15% hydraulic lime, and 10% pozzolan. The ratio of binder to hemp was changed from 2.12 to 2.77 (for low compaction) whereas water to binder ratio was kept constant as 0.5. It was concluded that the hemp-lime concrete had a great deformation capacity prior to compression failure when heavy compaction was applied whereas, at low compaction, hemp lime concrete had low resistance to compression. Barnat-Hunek et al. (2015) investigated the mechanical and thermal properties of hemp-lime concrete. Six batches of hemp-lime concrete were prepared and several tests were conducted to see how properties were being varied with different mix proportions. Three cubic specimens (100 mm dimension) were prepared from each batch to test bulk density and absorptivity. It was concluded that if the amount of hemp shives increased, absorptivity decreased, and bulk density increased. In addition, there was reduction in the compressive strength with increase in hemp percentage.

There are several experiments conducted on the thermal conductivity of hemp-lime concrete. Thermal conductivity is mainly varied by the moisture content and density of hemp lime concrete. Generally, hemp-lime concrete is highly porous with open and interconnected porosity. A study by Amziane and Arnaud (2013) showed that hemp lime concrete with the density of 200 and 600 kg/m^3 had a low thermal conductivity of 100 W/m. k. They compared hemp lime concrete to other types of concrete of same density (e.g. cellular concrete). Another study made by Benfratello et al. (2013) concluded that thermal conductivity was a function of the amount of hemp shives used in hemp lime concrete. Also, when hemp was increased from 20 to 40% of total weight of the mixture, the density raised from 369 to 611 kg/m^3 and thermal conductivity decreased from 140.8 to 94.7 W/m.k.

Collet and Pretot (2014a) studied the hygrothermal behavior of hemp-lime concrete walls made of precast blocks under environmental conditions (temperature and relative humidity). The blocks were made with mix proportions of 72% of lime by weight, 28% hydraulic lime, hemp to binder ratio of 0.65, and water to binder ratio of 1.2. A test wall of dimensions 2.3 m long, 2.1 m high, and 0.3 m thick was made by using blocks. Holes were provided in the blocks to place wooden frame for networks. Thermocouples were used for temperature measurement whereas sensors were used for measurement of both temperature and relative humidity. After four months of drying, the wall was stabilized to the ambient conditions at 23 °C and 40% relative humidity. Then, measurements were performed on uncoated and coated wall. The wall was coated with the breathable commercial lime-based coating. The coated wall showed a reduction in vapor pressure through the wall and delayed vapor diffusion because of additional moisture resistance.

In another study, Collet and Pretot (2014b) performed an experiment to know how moisture content and density of hemp-lime concrete affects the thermal conductivity. For this purpose, they made a wall (2.3 m long, 2.1 m high, and 0.3 m thick) with a different binder to hemp ratio. The binder was made of 78% hydrated lime, 15% hydraulic binder, and 10% pozzolanic binder. From the experiment, it was concluded that if the density of hemp-lime concrete increased by 54% of its original value, the thermal conductivity increased by 66.66% of its original value. Also, when the moisture content of hemp-lime concrete increased from 0 to 90%, the thermal conductivity increased by only 17.5%. Therefore, the density of hemp-lime concrete had a major impact on the thermal conductivity of hemp-lime concrete.

Walker and Pavia (2016) performed tests on the moisture transfer and thermal properties of hemp-lime concrete by varying binder. Six mixes of various mix proportions of binder, hemp, and water proportions were used to cast wall with dimensions 1.0 x 0.9 x 0.3 m^3. Out of six mixes, the materials like cement and lime of two specimens were completely replaced by ground granulated blast furnace slag (GGBS), metakaolin and remaining four specimens were made as it is with lime and cement. Walls were tested for water permeability, thermal conductivity, and heat capacity. The test results proved that binder type did not had any notable influence on permeability, thermal conductivity, and heat capacity of the specimens. Kinnane et al. (2016) investigated regarding acoustic absorption nature of hemp-lime concrete. Hemp-lime concrete walls (1.0 x 1.0 x 0.3 m^3) were built using six mixes by varying proportions of the binder. They divided six mixes into two sets (with pozzolans and without pozzolans). Specimens were tested using an impedance tube testing. The walls with pozzolans showed higher sound absorption coefficient at different frequencies of sound.

The above studies proved that using by-products like hemp shives can have many environmental advantages to the construction industry. However, there are no or limited studies on flax shives. Therefore, the project was started by expecting the same results may also be possible with flax shives. The main aim of this project is to use flax shives to make flax lime concrete as an insulation material in wall cavities of buildings. As a result, the use of conventional synthetic materials can be avoided. This paper presents the first stage of the project focusing on limited beam specimens to get an idea of the basic physical and mechanical properties of flax lime concrete.

2 EXPERIMENTAL STUDY

2.1 Materials

For the production of flax lime concrete, flax shives (with the length less than 25 mm) were obtained from a local farm in Nova Scotia, Canada. The average bulk density of flax shives was measured as 141 kg/m^3 by following standard procedure. The average bulk density was obtained by filling a cylindrical container (100 mm diameter and 200 mm height) in three layers with dry shives and compaction was done with a tamping rod (25 strokes per layer). The mixture of binder was prepared by fast mixing autoclaved lime (92% hydrated) and General Use Portland cement. They were mixed in a ratio of 4:1 (i.e. for every four cups of lime, one cup of cement was used). Then flax shives, mixture of binder and water were mixed in proportion of 4:1:1 for preparation of flax lime concrete (i.e. for every four cups of flax, one cup of binder and one cup of water was used). Three specimens (Beam 1, Beam 2, and Beam 3) were prepared for testing with a rectangular cross-section (152 mm x 51 mm) and length of 610 mm. An all-purpose burlap (jute fabric mesh) was used at the center of each specimen, to act as reinforcement for the specimen. The openings of the mesh (approximately 5 mm x 5mm) helped to provide an integration between flax lime concrete and the reinforcement. All specimens were tested under three-point bending.

2.2 Specimen Preparation

A formwork shown in Figure 1 was used to cast the specimens. Grease was applied to the formwork. Ten cups of binder was prepared initially. To prepare binder, Lime (8 cups) and cement (2 cups) were well mixed until a uniform mixture of the binder was obtained. Then, 10 cups of flax were taken into a bowl and 2.5 cups of binder were added to it. Flax shives and binder were mixed thoroughly by hand until a uniform mixture was obtained. Then, 2.5 cups of water were added and again mixed thoroughly by hand. All the mixture was transferred into formwork and compaction was done for 2 to 3 minutes using a tamping rod with 25 mm x 25 mm cross-section that is 150 blows per layer. The procedure was repeated, and the mixture was transferred into the formwork. When formwork was filled to half (2 layers of mixture), all-purpose burlap mesh was placed. Then, the same process was repeated until formwork was filled. Compaction was done in 4 layers. For each layer using the tamping rod, blows were given along the whole layer in the same direction. Then, the specimen was covered with a plastic cover and transferred to curing room. The specimen was placed in curing room for 7 days and then transferred to the lab to be dried at room temperature. After at least 28 days after casting the average density of the specimens was obtained 559 kg/m^3.

2.3 Test Setup and Instrumentation

For testing the specimens, a hydraulic loading system was planned to be used. But due to the sensitivity of the specimens, olden days method of placing weights at the center was used to test the specimens. So, to test the actual specimen the setup shown in Figure 2 was made. Two roller supports, two dial gauges one plate and weights were used for the testing specimen. The span between rollers was maintained as 558.8 mm. A small plate was placed on a specimen which was of negligible weight. This plate was helpful to measure deflection in the specimen by using dial gauges. Once everything was set, markings on specimen were done and weights were placed at the center of a plate and the dial gauges were read. The weights were added to each specimen until it failed.

Figure 1: Specimen preparation: (a) formwork; (b) adding binder to flax; (c) mixing binder with flax; (d) adding water to mix; (e) mixing water with flax and binder; (f) finally obtained mix; (g) formwork filled to half to place burlap; and (h) casting and compaction

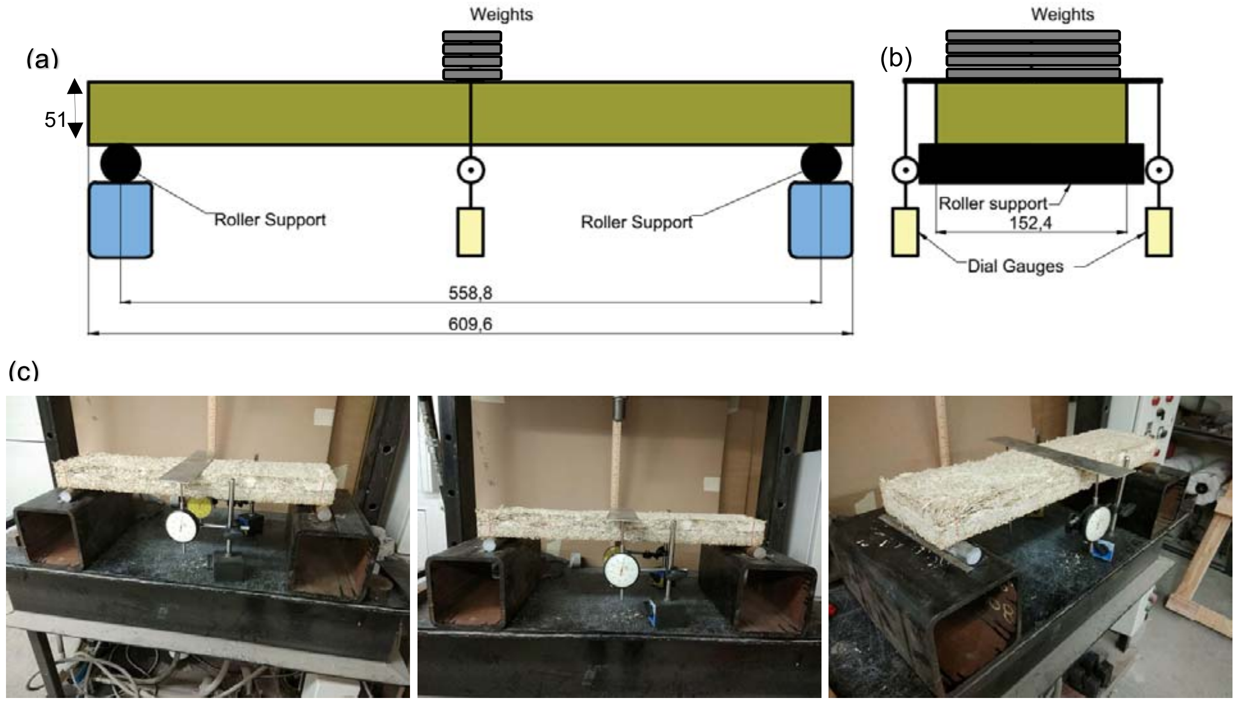

Figure 2: Test setup (dimensions in mm): (a) side view; (b) cross-section; and (c) photos of test setup

3 RESULTS AND DISCUSSION

3.1 Failure Modes

In all three specimens, flax shives were debonded on the application of weights. Due to debonding of flax shives, small flexure crack was initiated at bottom of the specimen, which was slowly propagated to the top by producing a cracking sound. The width of crack was observed to be increased on addition of weights. So, to provide support for the specimen all-purpose burlap was placed at half of the depth which can act as reinforcement. Burlap had shown a good effect on the specimen. Because it was observed that when the specimen was failed the crack can only propagate up to the depth where burlap was placed. So, the upper half of the specimen remained as it is without any damage. As shown in Figure 3, the cracks observed in all three specimens were similar to plain concrete specimen tested under bending, but the propagation of cracks was gradual.

Figure 3: Failure modes: (a) Beam 1; (b) Beam 2; and (c) Beam 3

3.2 3.2 Load-Deflection Behavior

Figure 4 shows the mid-span displacement of all three specimens. Since all the specimens had same mix proportions the mid-span displacement for all three specimens were nearly similar. In Figure 4(a), the point 'A' indicates the starting stage of cracking in the first the specimen. Once, after crack starts the first specimen produced about 2 mm of mid-span displacement before failing, where point 'B' indicates the failure of specimen. The Figure 4(a) also shows that displacement increased linearly with increase in load. In case of the second specimen, as shown in Figure 4(b), the total displacement produced was less than the first specimen. But, the displacement produced by second specimen from point 'A' to 'B' that is from starting stage of crack to failure was similar to first specimen. Figure 4(b) represented a linear relationship between load and displacement before Point "A". Figure 4(c) represents that total displacement produced by the third specimen was nearly equal to the first specimen and greater than the second specimen. All specimens produced nearly same displacement from cracking stage of Point "A" to failure at Point "B".

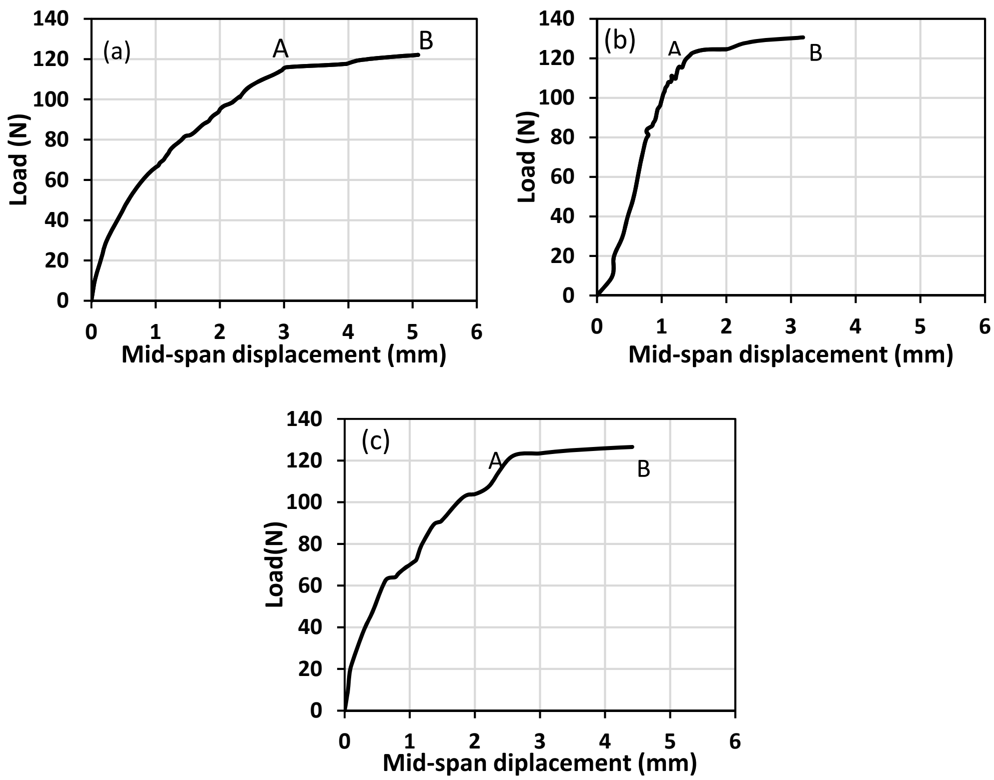

Figure 4: Load-deflection behavior: (a) Beam 1; (b) Beam 2; and (c) Beam 3

Table 1 shows the summary of the test results. The average loads at Point A and B were obtained 121 and 126 N, respectively. Also, the average displacements at Point A and B were obtained 2.3 and 4.2 mm, respectively. The displacement from Point A to B was almost 2 mm consistently. The average moment at mid-span at Point A (cracking) can be obtained as 17 N-m, which results in 1.0 MPa cracking strength of the flax lime concrete used in this study. The span/180 of the specimens provides a deflection of 3.1 mm, which is larger than deflection at cracking point. This means the blocks need to be stiffer. The solution can be placing the burlap mesh at a lower level closer to the flexural surface.

Table 1: Summary of test results

Specimen	Point A		Point B	
	Cracking Load (N)	Displacement (mm)	Failure Load (N)	Displacement (mm)
Beam 1	114	3.0	122	5.1
Beam 2	128	1.3	131	3.2
Beam 3	122	2.6	127	4.4
Average	121	2.3	126	4.2

4 CONCLUSIONS

In this paper, three beams specimens were prepared with a rectangular cross-section (152 mm x 51 mm) and length of 610 mm. The mix proportions were kept constant for all three specimens to check how loading and displacement were being varied for three specimens of same mix proportion. A layer of jute fiber-based fabric mesh (burlap) was also placed at the center of the specimens as reinforcement. After at least 28 days after casting, the average density of the specimens was obtained 559 kg/m^3. The specimens were tested under three-point loading up to failure. The following conclusions can be drawn:

- Failure crack in all three specimens was similar to flexure crack in the concrete. In all three specimens, the crack was started at center and propagated in an upward direction. Whereas the failure crack was not observed from center to the top surface since the burlap was placed at the center of depth. From the point of cracking to failure, the specimens did not take much load.
- From load-deflection curve, it can be observed that all the three specimens on average took about a load of 121 N at cracking, which corresponds to 1.0 MPa flexural strength. The total displacement produced by specimens on average was 4.2 mm. But, all the three specimens deflected by the same amount from cracking point to failure point.
- The usage of burlap at the center has provided good support to the specimen. But still, research is going on to change the position of burlap and then using flax lime concrete as insulation material. This paper is a part of an in-progress project focused on the application of flax lime concrete for prefabricated blocks for filling the cavity of building walls as insulation.

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