Study of Mechanical Properties for Masonry Produced Using Hemp and Lime in The form of Interlocking Blocks

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Abstract

This objective of this article was to present a production method for masonry that uses hemp shiv, lime and water as the composition for interlocking blocks. The aim was to identify the best condition for substituting lime with hemp shiv as much as possible in order to develop energy efficient construction material. The tests performed included water absorption, dry density test, and compressive test according to the TIS109-2517. Comparisons were made for samples containing hemp at 100, 200, 300, and 400 grams per block or from 2.86 – 26.67 per cent alternative material per block. It was found that the use of lime as the binding material for hemp shiv resulted with interlocking blocks with good physical appearance. However, there are limitations on strength and water absorption properties. All of the conditions tested resulted with a compressive strength of less than 0.5 MPa and the water absorption test was not able to be carried out. The results of this research indicated that for the production of interlocking hempcrete blocks using only lime as the binding material had limitations on its strength and can not be used in construction work. Cement is still required as binding material for this purpose.

Keywords: Interlocking block, Hempcrete, Non-load baring masonry

1. Introduction

Construction is one of the major contributors to global warming with emissions from construction activity and embedded emission in construction material from material extraction and production process. The development of low carbon embodied construction material will reduce the carbon footprint of buildings and provide better alternative for green and sustainable construction [1]. With the global concern and the green building movement in Thailand, bio-based masonry alternatives are options that must be explored. Previous studies indicated that the production of conventional construction materials produce larger amounts of pollution and required higher energy consumption in comparison to bio-based alternatives [2]. The application of bio-based materials offers potential reduction in energy requirement and pollution loading. Furthermore, they have low thermal conductivity which is beneficial for building's energy efficiency. Due to Thailand's Energy Conservation Promotion Act 1992 and its amendment in 2017, it is necessary to find alternative materials that are economically efficient as well as energy efficient as the existing thermal insulators in the market are expensive [3].

Although there are a variety of agricultural wastes in Thailand that can be used, hemp is a potential new economic crop that offers multiple benefits. At the present the actual amount of hemp supply is not exact, as of 9 June 2022, according to the Food and Drug Administration's Narcotic Control Division website there are 3,419 registered hemp plots which are growing approximately 180,299 hemp trees. However, with the passing of the new law the supply of hemp shiv is expected to sustain production at the commercial scale and using hemp shiv in as a masonry component will close the waste loop for hemp [4], thus contributing directly to the reduction of embodied carbon for the material and also support the government's bio-economy scheme. Furthermore, in addition to its great thermal properties, hempcrete is also fire resistant and passed the 75-minute European burn test [5, 6].

The use of hempcrete improves the overall indoor air quality and temperature [7].

Interlocking block production method is a masonry production method that is simple and allows the utilization of various components [8]. It is basic and have low energy requirements. The blocks can also be stacked on top of each other once dried to safe storage space.

The objective of this research to identify the proper mix of hemp for the production of energy efficient masonry, using interlocking block production method. The hempcrete samples will be tested based on the TIS109-2517 standard for sampling and testing concrete masonry units.

2. Research Methodology

This research is a case study on the properties of interlocking blocks produced using dry hemp shiv with hydrated lime as the binding material. The sample materials in this research were produced as interlocking blocks and the tests and result analysis were performed as shown in 2.1 and 2.3 respectively.

2.1 Materials

Materials used for the production of interlocking blocks included hydrated lime, water and dry hemp shiv. Dry hemp shiv sized 0.075 – 9.51 mm as shown in Figure 1 were used in this test. The hydrated lime used was TPI Super Dolomite 500 as shown in Figure 2. It has a pH level of 11 and no less than 21% magnesium and 40% calcium.

Figure 1 Dry hemp shiv

Figure 2 Hydrated lime

2.2 Production of interlocking block samples

The production process for interlocking blocks samples is summarized as in Figure 3 below. In this test, 6 component mixtures were used to produce interlocking blocks samples for the test. The components used in the mixtures are as shown in Table 1. Hemp shiv were used as aggregates at 2.86, 4.62, 6.67, 10.00, 15.00, and 26.67% to make the interlocking blocks. Water is added gradually to the dry mixture and the wet mixture is to be checked for excess water by squeezing it. If the mixture holds together after they are squeezed without excess water dripping out then it is ready to be put into the interlocking mold to be shaped. Figure 4 shows the wet mixture ready for molding and Figure 5 is the hempcrete interlocking block produced. Each block is 12.5 x 25.0 x 10.0 cm. After the interlocking blocks are formed, aerate them for 28 days in the shade before performing property tests accordingly. Prepare 5 samples for each mixture.

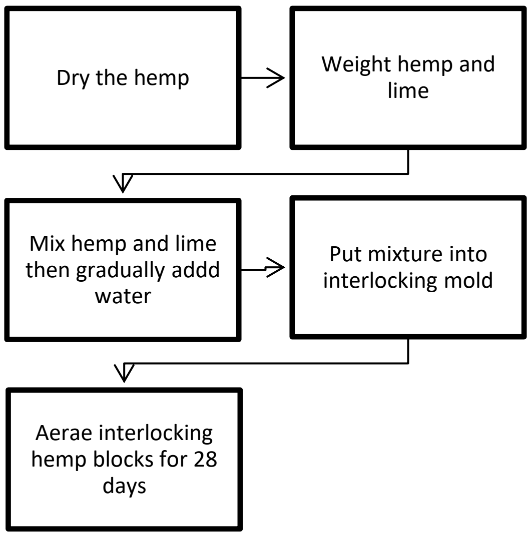

Figure 3 Hempcrete interlocking block processing

Table 1 Mixture for production of 1 interlocking block sample.

No.	Weight of component (kg)			% Alternative material	% Moisture
	Dry hemp shiv	Hydrated lime	Water		
1	0.10	3.50	0.70	2.86	19.44
2	0.15	3.25	0.90	4.62	26.47
3	0.20	3.00	1.00	6.67	31.25
4	0.25	2.50	1.10	10.00	40.00
5	0.30	2.00	1.20	15.00	52.17
6	0.40	1.50	1.50	26.67	78.95

Figure 4 Hemp-lime mixture with appropriate moisture for molding.

Figure 5 Interlocking hempcrete block molding

2.3 Test and Result Analysis

The properties of the interlocking blocks were tested using absorption test, dry density test and compressive test according to TIS 109-2517. Sampling and testing method for Cementous construction material was used where 5 samples of each mixture were prepared per test. The results obtained were compared to the standard for community product for interlocking blocks (TCPS602/2547) where the standard compressive strength for load baring blocks is specified at no less than 7 MPa and non-load baring blocks must have a compressive strength of no less than 2.5 MPa and absorption property as shown in Table 2. The samples weigh 3,711.2, 3,229.4. 3160.4, 2,662.6, 2,44.9 and 1,821.3 g for the blocks with 100, 150, 200, 250, 300, and 400 g of hemp respectively.

Table 2 Absorption property for interlocking block for load baring blocks according to TCPS 602/2546.

Oven-dried weight of interlocking block (kg/m^3)	Highest average water absorption ratio for 5 interlocking blocks (kg/m^3)
≤1,680	288
1,681 to 1,760	272
1,761 to 1,840	256
1,841 to 1,920	240
1,921 to 2,000	224
> 2,000	208

3. Results and Discussion

3.1 Experimental results for identification of component ratio for interlocking block production

First an interlocking block with standard properties according to the TCPS 602/2547 for load baring block was produced. From the experiment it was found that 1 load baring interlocking block using 1 kg of Portland Cement Type 1, 4.5 kg of soil and 10% moisture can produce an interlocking block with good physical properties as shown in Figure 7. This block has a compressive strength of 8 MPa, dry density of 1,763 kg/m^3 and absorption ration of 239 kg/m^3 which falls in the category for load baring interlocking block based on Table 2 for oven-dried weight of 1,761 – 1,840 kg/m^3 with absorption ratio of less than 256 kg/m^3.

The production of interlocking hempcrete blocks according to the components shown in Table 1 resulted in interlocking blocks with good physical characteristics as shown in Figures 6 – 9 respectively.

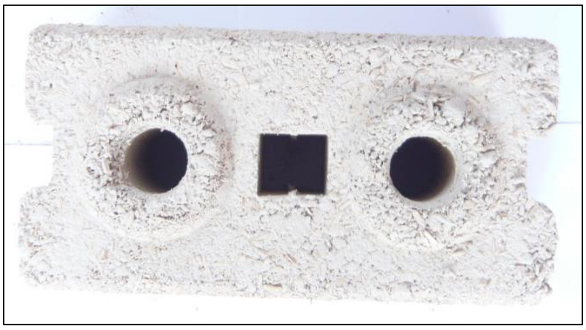

Figure 6 Hempcrete with 100 g of hemp

Figure 7 Hempcrete with 150 g of hemp

Figure 8 Hempcrete with 200 g of hemp

Figure 9 Hempcrete with 250 g of hemp

Figure 10 Hempcrete with 300 g of hemp

Figure 11 Hempcrete with 400 g of hemp

The results for the compressive strength test are as shown in Table 3 which indicated the hempcrete samples have comprehensive strength ranging between 0.35 – 0.39 MPa. All the scenarios have compressive strength of less than the minimum standard of 2.5 MPa for non-load baring interlocking blocks. This showed the limitations of using hydrated lime as the only binder. However, these results are not an unexpected surprise as previous researches on production of hempcrete with lime as the binding [6] had also shown results with lower compressive strength. The difference may also be due to the different method for molding.

It should be noted that it was not possible to perform the water absorption test on the samples as the sample collapsed in water. This is because when hempcrete is soaked in water the lime dissolves and can not hold the shape of the interlocking block. It is more evident in the samples with lesser amount of hemp shiv. For example, the hempcrete using 200 g of hemp that is soaked in water for the water absorption test will result as in Figure 12 where the shape failed to hold. The result of the water absorption test that there are significant limitations in using lime as the only binding material.

Table 3 Compressive test for interlocking hemp block samples

No.	Hemp mix (g)	Weight before compressive test (g)	Maximum compressive strength (Mpa)
1	100	3632.0	0.38
2	150	3247.9	0.39
3	200	3134.7	0.35
4	250	2720.0	0.35
5	300	2713.8	0.38
6	400	1732.3	0.35

* Averaged value from compressive strength test of 5 samples per mixture.

Figure 12 Hempcrete (200 g hemp) after soaked in water.

3.2 Discussion

Although the result of this experiment showed that using only hydrated lime and hemp mixture can not produce up to standard interlocking blocks for application it does not mean that the hempcrete is not a viable option for construction material. There are research evidence and applications of hempcrete that indicate that they are beneficial construction material in terms of being lightweight and contribute to good indoor air quality [4, 5, 7]. The production of hemp-based interlocking blocks will also be direct contribution to lowering carbon emissions from the construction sector and aligned with the bio-circular economy concept. The mechanical properties can be improved with the addition of other additives or binding materials. Mixture of other waste materials such as fly ash, bamboo or rice husk ash may also be considered to minimize the use of concrete which has very high carbon footprint.

4. Conclusion

The results of the interlocking hempcrete test showed that the strength of hempcrete is very low and at the same time, they are very similar despite of the amount of hemp shiv used. The compressive strengths were 0.38, 0.39, 0.35, 0.35, 0.38 and 0.35 MPa for the hempcrete blocks with 100, 150, 200, 250, 300, and 400 grams of hemp respectively. Meanwhile, the samples were not able to be tested for water absorption therefore it did not complete the requirements of the TIS 109-2517. In this research, using only hydrated lime as the binding material may have caused the limitations to the mechanical properties of the hempcrete interlocking block. Therefore, to improve the strength and applicability of the hemp-based interlocking block additional binding material such as Portland cement should be used.

Follow-up research to find out the appropriate mixture between hemp shiv, hydrated lime and cement in order to achieve the required properties based on the TCPS 602/2547 standard based on the TIS 109-2517 sampling and testing method should be should be carried out. There are sufficient data from literature reviews that hempcrete is a viable construction material with multiple environmental and health benefit as well as being energy efficient masonry. In addition to that, with the progress of legalizing and promoting hemp as an economic crop in Thailand, soon there will be surplus supply of materials and development of the hemp-based masonry will be added benefit to the life cycle of hemp products.

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References

[1] Huang, L., Krigsvoll., G., Johansen, F., Liu, Y., Zhang, X. (2018). Carbon emission of global construction sector. *Renewable and Sustainable Energy Reviews, Elsevier,* 81(P2), pp. 1906-1916.

[2] Madurwar, M. V., Ralegaonkar, R. V., Mandavgane, S. A. (2013). Application of agro-waste for sustainable construction materials: a review. *Construction and Building Materials,* 38, pp. 827-878.

[3] Intata, S., Atthajariyakul, S., Chirajoj, R. (2006) A study on the selection of materials for energy efficient house. *Thailand's 2nd Conference on Energy Network of Thailand*, Nakhon Ratchasima, 27-29 July 2006, pp. 90-95.

[4] Pittau, F., et al. (2018). Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls. *Building and Environment*, 129, pp. 117-129.

[5] Elfordy, S., et al. (2008). Mechanical and thermal properties of lime and hemp concrete ("hempcrete") manufactured by a projection process. *Construction and Building Materials,* 22(10), pp. 2116-2123.

[6] Demir, Ismail & Doğan, Cüneyt. (2020). Physical and Mechanical Properties of Hempcrete. The Open Waste Management Journal. 13. 26-34. 10.2174/1874312902014010026.

[7] Shang, Y., Tariku, F. (2021) Hempcrete building performance in mild and cold climates: Integrated analysis of carbon footprint, energy and indoor thermal and moisture buffering. *Building and Environment*, Vo 206, December 2021.

[8] Pechvipart, J. (2006) Legend of soil cement blocks and interlocking blocks part 2 (2006). Science and Technology Journal, Year 21, Vol.2, pp 57-62.