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Mechanical Properties of Pre-Compressed Hemp-Lime Concrete

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To answer different problems set by the 21st century, European Union is constantly updating the old and adapting new directives and regulations. One of these directives is 2010/31/EU as a piece of Energy package which sets forth a goal to reduce primary energy use by 20% and to achieve 20% reduction in greenhouse gas emissions by 2020. It also sets a task for all buildings built after 2020 to be zero-energy buildings. To achieve these goals, next to existing building materials, a new, innovative, and more sustainable materials needs to be studied and implemented. One of these possible materials is lime-hemp concrete – a self-bearing thermal insulation material that consist of lime and hemp shives. Its mechanical properties seem promising, and thermal conductivity below 0,08 W/m*K is significant result for a material that sequesters more CO2 then is created in its life cycle. In the paper an effect of pre-compressed of hemp-lime mix before curing is studied. Two different binders were chosen (dolomitic lime and dolomitic lime with metakaolin) and three different compaction ratios – 50, 25 and 0 %. As expected, the compaction has a direct impact on compressive strength, as well as flexural. The elevated densities also have a negative effect on thermal conductivity, yet not as much if the same density would be achieved with addition of more binder. This method could help to produce lime-hemp concrete materials with better strength/thermal conductivity ratio. A further research of improved drying techniques is needed, as the samples had softer inner part, due to excess moisture during curing.

KEYWORDS: CO_2 neutral, hemp-lime concrete, pozzolans, pre-compression

Introduction

In recent years European Union has taken several important steps to make its energy policy more sustainable due to various reasons – economical (Filippini *et al* 2014), security (Gracceva and Zeniewski 2014) and environmental (Desideri *et al* 2014). One of those steps were the passing of directive 2010/31/EU (DIRECTIVE 2010/31/EU) "On the energy performance of the buildings" as a piece of Climate and Energy package which one of the goals are to reduce primary energy use by 20% and to achieve 20% reduction in greenhouse gas emissions by 2020 (Broin *et al* 2014). And the passed directive specifies these goals more regarding construction sector and building material industry.

Thus one of the most important points of this directive is the requirement for all buildings built after year 2020 to be zero-energy buildings (DIRECTIVE 2010/31/EU). To accomplish this requirement a shift in building material industry towards new, innovative, sustainable and ecological building materials will be needed (Pacheco-Torgal 2014). And one of the new material which has a potential to be used more widespread to meet these new demands is natural insulation material made out of hemp and lime.

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This material uses inner part of the hemp stalk – hemp shives – a byproduct of hemp fiber manufacture as a filler and hydraulic lime as binder, it is known as lime-hemp concrete (LHC as referred in this article), hempcrete, hemp-lime and green concrete (Bruijn and Johansson 2014). It is mostly used as a self-bearing wall thermal insulation material in combination with structural timber frame. Developed in France in late 80`s (Walker and Pavía 2014) has now spread to other European countries like UK (Evrard *et al* 2014), Ireland, Poland, but have not yet acquired a significant amount of recognition. To understand the advantages of this material it will be reviewed through the prism of EU regulation N305/2011 (REGULATION (EU) No 305/2011) which sets forth 7 basic requirements for construction works and building materials:

_ MECHANICAL RESISTANCE AND STABILITY – it has much higher mechanical resistance as typical thermal insulation materials, as it does not need any extra layers with materials and a plaster can be applied straight on the surface (Elfordy *et al* 2008).

_ SAFETY IN A CASE OF FIRE – the addition of mineral binders can improve hemp fire resistance up to class B by EN 13501-1 (Sassonia *et al* 2014) compared to typical E class of natural fiber insulation materials without mineral binder (Kyma and Sjo 2008).

_ HYGIENE, HEALTH AND THE ENVIRONMENT – LHC does not contain VOC`s or any other harmful substances. It also has great moisture buffering capabilities, which improves indoor air quality by preventing fungus and mold growth – which is a cause for allergic diseases (Lea *et al* 2010, Bruijn and Johansson 2014).

_ SAFETY AND ACCESSIBILITY IN USE – no major advantages/disadvantages.

_ PROTECTION AGAINST NOISE – due to its porous and fiber structure yet higher density than regular insulation materials, LHC insulates sound with both absorption and reflection providing better sound insulation at equal thickness (Carezo 2005).

_ ENERGY ECONOMY AND HEAT RETENTION – LHC has a relatively good thermal insulation properties – λ below 0,08 (W/m*K) which makes it compatible with other insulation materials (Sassonia *et al* 2014, Benfratello *et al* 2013) .

_ SUSTAINABLE USE OF NATURAL RESOURCES – it has been proven by several researchers that the whole manufacture process of LHC sequester more CO_2 then is released into the atmosphere, as the hemp plant takes up carbon dioxide in growing process and lime also gathers CO_2 in its hardening process. The amount of carbon dioxide sequestered is around 35 kg for 260 (Ip and Miller 2012) or 300 (Shea *et al* 2012) mm thick LHC wall.

As can be seen from the review, the LHC could be rather appropriate material to answer the challenges of the modern society. Yet it is not fully researched and tested in different environments, and the technologies regarding its manufacture, testing and disposal can also be improved.
The goal of this research is to establish the effect of pre-compression of ready-mixed LHC material at different ratios and to test the correlation between density/thermal conductivity/ compressive strength/ flexural strength. The material will be compressed at three different ratios (0%, 25% and 50% from initial height) and two distinct binders will be used. The aim is to achieve better thermal conductivity/strength ratios than could be achieved by adding additional amounts of binder.

Methods

Materials

The hemp shives were not specially treated at laboratory, but were obtained from hemp processing plant in Kraslava, Latvia, as by-products of hemp fiber production. Shives are not fully separated from dust and some fiber, which has a negative effect on LHC properties. Granulometry of hemp shives can be seen in Fig. 1 and also other characteristics in Table 1.

Table 1

Main characteristics of used hemp shives

Property	Value
Bulk density	50 kg/m3
Avg. length	1,5 cm
Max. length	5,5 cm
Avg. width	0,3 cm
Max. width	0,6 cm
Moisture content	13,2 %
Thermal conductivity (bulk form)	0,052 W/m*K

Fig. 1

Size and shape of hemp particles

Fig. 2

Moulds for compression

The first binder (samples K1 – K3) used is formulated lime that has been elaborated during previous tests (Sinka *et al 2013)*, it consists of 60% by mass DL60 dolomitic lime, produced by “Saulkalne” Ltd. and 40% metakaolin, obtained by burning kaolin clay at 800^0 C. In binder/sand ratio 1:3 it can obtain compressive strength as high as 10 MPa. Second binder (samples K4 – K6) is pure dolomitic lime which has also showed promising properties with hemp shives.

Sample preparation and curing

The proportion between hemp and binder was also elaborated during previous tests, so a 0.375/0.625 hemp/binder ratio by mass proportion were used, binder/water ratio – 0.66:1. Laboratory drum mixer was used to mix the ingredients. First, the hemp shives were put in the mixer along with a half of water necessary and mixed for 3 minutes, then the binder were put in, mixed for another 2 minutes, and then the rest of the water followed and the preparation continued for 3 minutes. After this process the binder had been uniformly distributed and was covering the surface of the shives.

Afterwards the ready mix were put in specially made moulds, which were designed to apply constant pressure to LHC defined by the ratio of height between uncompressed and compressed specimen. Mould is made out of 30 mm thick waterproof plywood, dimensions of uncompressed sample – 350*350*120 mm (see Fig.2). In all corners there are threaded rods with nuts which when tightened compress the sample by maximum 60 mm, which gives maximum compressive ratio of 50%. In this particular test three different ratios for both binders were used – 0% (K3 and K6), 25% (K2 and K5) and 50% (K1 and K4).

Before the ready mix was put, the moulds were covered with oil, to prevent the sticking of LHC to the mould. The samples of 0% compressive ratio were put in the moulds, slightly tamped and covered. When making the 25% and 50% samples, the mould were filled with the mix, and then the nuts were tightened and the both sides of the mould closed in on each other by 30 and 60 mm.

The applied compression were removed after three days of curing in laboratory conditions (55±10 % RH and 20±2 ^{0}C). After six days from the fabrication the samples were completely demoulded and placed vertically for quicker drying. The specimens were then allowed to dry in the same conditions and periodic weighting of the samples were done, to see if the drying process still continues. The evaporation of the water for all samples ended after two months, then the testing started.

Testing

Before the thermal conductivity test, the density of the samples were calculated by measuring the dimensions and weighting the samples. The thermal conductivity were measured in guidance of EN 12667 and EN 12939, using hot-plate method and FOX500 heat-flow measurer.

To test the compressive and flexural strength, the samples were sawed in necessary dimensions. The dimensions were 100*100*(height) mm cubic forms for compressive tests –three parallel and two crosswise to the tamping direction, one 100*250*height mm piece for each flexural strength. Mechanical tests were performed on ZWICK Z100 universal testing machine. The pressure applied – 6 mm/min and a force-deformation diagram were recorded in the process. For compressive strength a stress at 10% deformation were recorded, for compressive crosswise and flexural – until failure.

Results

When the samples ceased to show any signs of drying, the density of the samples were calculated by measuring and weighting the samples. Afterward a thermal conductivity test on FOX500 were performed, the results of test can be seen in Table 2.

The first thing that was observed when working with the samples – that the back side of the sample, is not so hard as the front side, as from the plates with no compression applied there were even some small bits that were crumbling of the back side.

When the samples were sawed into pieces, the problem revealed was even bigger, as the material had a strong layer only at the outside surface, the inner part of the LHC plate was softer. For the samples without compression the inner part was too soft for a flexural strength prism to be sawed off, lime was in a form of powder.

During the compressive strength test parallel to the direction of compaction none of the samples showed any particular breaking point and deformed evenly.

Table 2

Density and thermal conductivity of the samples

Sample name	Density, kg/m^3	Thermal cond. W/(m*K)
K1	540	0,086
K2	397	0,076
K3	330	0,070
K4	461	0,079
K5	367	0,072
K6	345	0,071

Table 3

Mechanical properties

Sample name	Compressive strength, MPa	Compressive strength (crosswise), MPa	Flex. Strength, MPa	Flex. Strength (crosswise), MPa
K1	0,266	0,056	0,021	0,061
K2	0,154	0,051	0,011	0,029
K3	0,133	-	-	-
K4	0,181	0,041	0,032	0,054
K5	0,136	0,031	0,013	0,028
K6	0,125	-	-	-

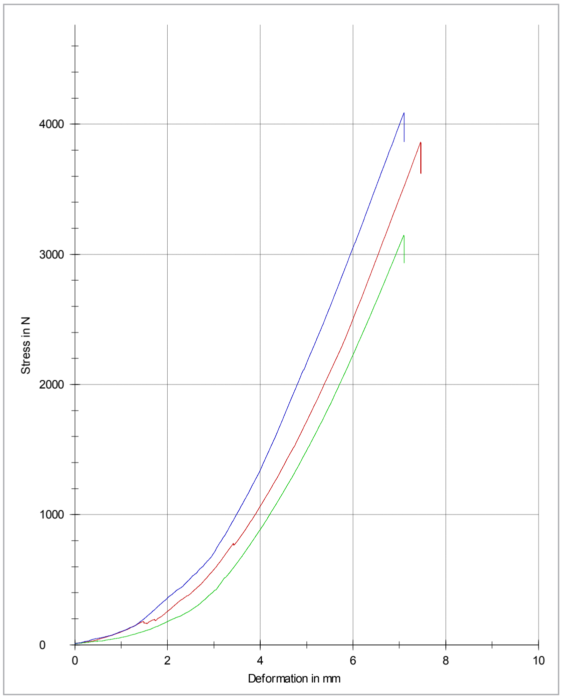

Fig. 3

Force-deformation diagram for K1 in compression

In **Fig. 3.** a force-deformation diagram for the K1 three samples for compressive test can be seen.

It was observed that after removal of the pressure K1 and K4 samples most notably showed elastic deformation. These samples also displayed the best stress resistance and was removed from the testing machine in one piece, whilst the other samples failed.

It must be noted, that compressive test crosswise compaction direction shows a distinctive breaking point in the diagram, also the material itself failed and crumbled completely. The value is about 1/3 of the compressive strength.

The material showed flexural deformation pattern similar of rigid materials - steady force-deformation line, then a forming of a crack in the middle of the sample and a failure. Flexural strength was there times lower than crosswise flexural strength, because material had soft inner core and rigid surface, which could withstand the applied force much better when positioned parallel to the force.

Discussion

Firstly, as can be seen from Table 2. – compaction has a direct effect on density, yet the compaction coefficient and density doesn't correlate precisely, as , for example, the difference between K1 and K3 should be 0,5, yet it is 0,61. This is due to fact that the densities of samples before compression need to be similar, but it was not controlled, material was freely put in to moulds without tamping before compaction, but the K4 and K6 samples were tamped slightly. To evade this error in future, density of the samples need to be measured before compaction and similar results must be achieved.

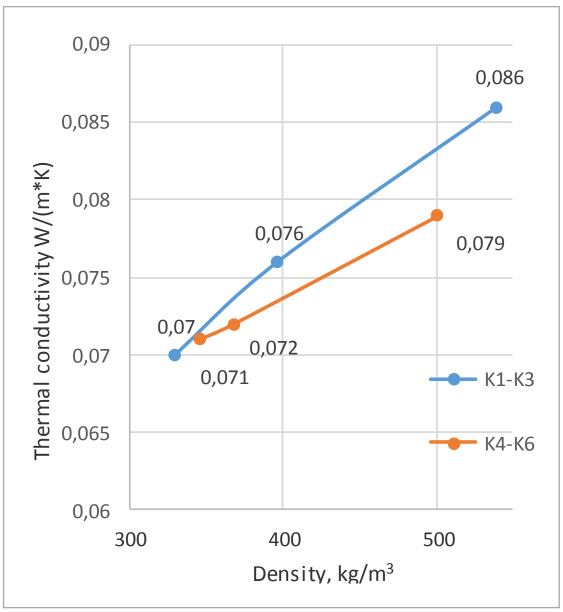

Fig. 4

Thermal conductivity/ density correlation

Secondly, the correlation between density and thermal conductivity can be seen from **Table 2** and **Fig. 4.** and as expected – the thermal conductivity rises as the material becomes denser, because there are less air and better conducting lime particles are closer together. But on other hand – the increase in the density doesn't correlate with the available information in literature, where for the same amount of shives, different quantities of lime were added (Bruijn and Johansson 2014) but for similar densities much higher thermal conductivity was obtained. It can be explained by the fact that in this particular experiment the shives fill the empty air pores in compression process, not only lime, which worsens the thermal conductivity of LHC.

From the chart (Fig. 4) it can also be seen that K4-K6 shows slightly lower density and thus also lower thermal conductivity. This could possibly be only a technological error, as it is hard to achieve identical density of the material when it is put into the molds before compaction process. The average thermal conductivity/density ratio for particular materials is about 0,005 W/m*K for every 50 kg/m3.

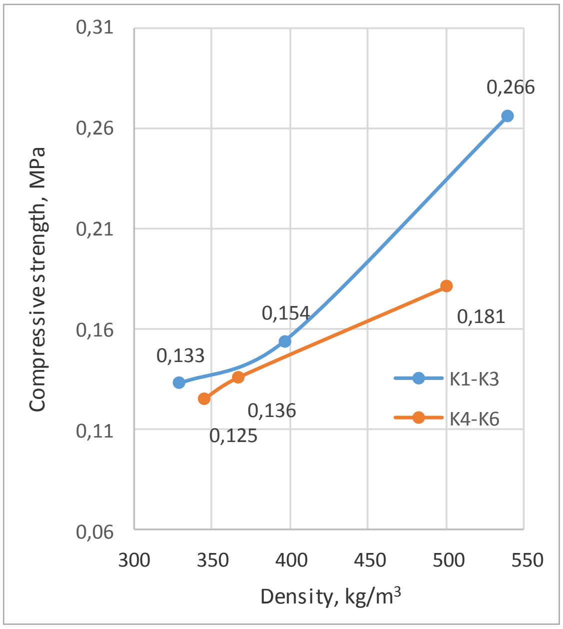

Fig. 5

Compressive strength/ density correlation

Although lime is considerable a rigid material, force-deformation diagram acquired from Zwick z100 and showing K1 samples [Fig. 3.], calls for rethinking. Because it was observed that the inner part of the LHC slab is not fully hardened, it is safe to say that the inner part of the slab worked in elastic phase, while the outer part remained intact. This can be affirmed by the fact, that when removing some of the samples from the testing machine, they were virtually intact, contrary of the samples which were created in previous experiments and crumbled after the tests.

It can be seen from Table 3 and Figure 5 that density also has direct correlation with compressive strength – as the density rises, the compressive strength also rises. This can also be explained by the shorter distances between shives which provides more contact zone. The compressive strength loss with decreasing density is exhibited by both binders, although pure DL lime (K4-K6) binder showed poorer performance, which was expected, as the binder itself has a smaller compressive strength (Sinka et al 2013).

From Table 3 there can also be seen that compressive strength for LHC materials crosswise of the compaction direction are significantly lower than in parallel direction. This is due to the fact that without compression of the samples in this direction there are more open and empty spaces between shives, so a smaller contact zone and more voids to be filled by breaking shives. Compressive strength crosswise is around 4 – 6 times lower than the regular compressive strength.

For flexural strength test only K1, K2, K4 and K5 prisms were sawed (Table 3), as K3 and K6 samples were too soft and broke in the preparation process. The values of flexural strength tests can be seen in Table 3. They were greatly influenced by the softer inner part of the slab as only the both outer crusts of the material worked in compression and strain. If obtained results are compared with similar studies (Walker et al 2014) then it can be seen that the inner softer part of the samples negatively influenced the performance. The flexural strength needed to be around ¼ of compressive strength, which is the approximate result of flexural strength crosswise.

Conclusions

1 A correlation of LHC between density and thermal conductivity were confirmed, it is around 0,005 W/m*K for every 50 kg/m3 gained. Yet these observations don't match with results from previous test, so it is possible to assume that the inner voids were filled with more shives then in previous tests, which allowed to improve the thermal conductivity.

2 For the most compacted samples, the material in compression works in partly elastic deformation phase, as the most deformations are exhibited by the inner part of the slab and rigid outer layers didn't get invertibly compressed.

3 The insufficient hardening of the inner parts of the slabs is considered to be partly because of the excess moisture that couldn't evaporate fast enough through hardly compressed samples. This could be prevented in future with controlled and excessive drying of the samples. Also the relatively high density makes it harder for lime to carbonate, as this process can take even years for dense materials, such as mortars.

4 Densities of the samples before compaction need to set identical, so that the densities of ready-made material differates just as much as compaction coefficient, which would make the test more accurate.

5 LHC materials are one of the materials that could answer to challenges set by modern society, as it is CO2 neutral, have good thermal capabilities and satisfying mechanical properties.

References

Balčiūnas G., Vėjelis S., Vaitkus S., Kairytė A. 2013. Physical Properties and Structure of Composite Made by Using Hemp Hurds and Different Binding Materials. In: Procedia Engineering. Vol. 57, 159-166.

Benfratello S., Capitano C., Peri G., Rizzo G., Scaccianoce G., Sorrentino G. 2013. Thermal and structural properties of a hemp–lime biocomposite. In: Construction and Building Materials. Vol. 48, 745-754. http://dx.doi.org/10.1016/j.conbuildmat.2013.07.096

Broin E. O., Mata E., Göransson A., Johnsson F. 2013. The effect of improved efficiency on energy savings in EU-27 buildings. In: Energy. Vol. 57, 134-148. http://dx.doi.org/10.1016/j.energy.2013.01.016

Bruijn P. S., Johansson P. 2014. Moisture transport properties of lime-hemp concrete determined over the complete moisture range. In: Biosystems Engineering. Vol. 122, 31-41. http://dx.doi.org/10.1016/j.biosystemseng.2014.03.001

Carezo V. 2005. Mechanical, thermal and an acoustic material based on vegetable particles: experimental approach and theoretical modeling. Available at: http://theses.insa-lyon.fr/publication/2005ISAL0037/these.pdf (accessed 11 June 2014).

Desideri U., Arcioni L, Leonardi D., Cesaretti D., Perugini P., Agabitini E., Evangelisti N. 2014. Design of a multipurpose "Zero energy consumption" building according to European directive 2010/31/EU: Life cycle assessment. In: Energy and Buildings. 2014.

DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings.

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. In: Construction and Building Materials. Vol. 22, 2116-2123. http://dx.doi.org/10.1016/j.conbuildmat.2007.07.016

Evrard A., Flory-Celini C., Claeys-Bruno M.,De Herde A. 2014. Influence of liquid absorption coefficient on hygrothermal behavior of an existing brick wall with LimeHemp plaster. In: Building and Environment. Vol. 79, 90-100. http://dx.doi.org/10.1016/j.buildenv.2014.04.031

Filippini M., Hunt L. C., Zoric J. 2014 Impact of energy policy instruments on the estimated level of underlying energy efficiency in the EU residential sector. In: Energy Policy. 2014, Vol. 69, 73-81. http://dx.doi.org/10.1016/j.enpol.2014.01.047

Gracceva F., Zeniewski P. 2014. A systematic approach to assessing energy security in low-carbon EU energy system. In: Applied Energy. Vol. 123, 335-348. http://dx.doi.org/10.1016/j.apenergy.2013.12.018

Ip K., Miller A. 2012. Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK. In: Resources, Conservation and Recycling. Vol. 69, 1-9. http://dx.doi.org/10.1016/j.resconrec.2012.09.001

Kyma H. R., Sjo A. M. 2008. Flax and hemp fibres as raw materials for thermal insulations. In: Building and Environment. Vol. 43, 1261-1269. http://dx.doi.org/10.1016/j.buildenv.2007.03.006

Lea A. D. T., Maaloufa,C., Maia T.H., Wurtzb E., Collet F. 2010. Transient hygrothermal behaviour of a hemp concrete building envelope.. In: Energy and Buildings. Vol. 42, 1797-1806.

Pacheco-Torgal F. 2014. Eco-efficient construction and building materials research under the EU Framework Programme Horizon 2020. Construction and Building Materials. Vol. 51, 151-162. http://dx.doi.org/10.1016/j.conbuildmat.2013.10.058

REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

Sassonia E., Manzia S., Motoria A., Montecchid M., Canti M. 2014. Novel sustainable hemp-based composites for application in thebuilding industry: Physical, thermal and mechanical characterization. In: Energy and Buildings. Vol. 77, 219-226.

Shea A., Lawrence M., Walker P. 2012. Hygrothermal performance of an experimental hemp–lime building. In: Construction and Building Materials. Vol. 36, 270-275. http://dx.doi.org/10.1016/j.conbuildmat.2012.04.123

Sinka, M., Sahmenko, G. 2013. Sustainable Thermal Insulation Biocomposites from Locally Available Hemp and Lime. In: Environment. Technology. Resources. Proceedings of the 9th International Scientific and Practical Conference. Vol. 1, 73-77.

Walker R., Pavía S. 2014. Moisture transfer and thermal properties of hemp–lime concretes. In: Construction and Building Materials. Vol. 64, 270-276. http://dx.doi.org/10.1016/j.conbuildmat.2014.04.081

Walker R., Pavia S., Mitchell R. 2014. Mechanical properties and durability of hemp-lime concretes. In: Construction and Building Materials. Vol. 61, 340-348. http://dx.doi.org/10.1016/j.conbuildmat.2014.02.065

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