UDC 681.12

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RESEARCH OF ENERGY EFFICIENT STRUCTURAL AND COMPOSITE MATERIALS

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Abstract

The mechanical and thermal properties of lime-hemp concrete (hempcrete) made in three different mixtures were analyzed in the paper. These mixtures were prepared with a binder-to-filler (hemp and flax shives) ratio of 2.2:1, using quicklime as the primary binder. Some mixtures included a blend of binders, with 10% lime substituted by either cement or organic sapropel.

The research findings were compared with those described in our previous research. Research of lime-hemp concrete has shown - that for the mixtures prepared using binders and filler (hemp and flax shives) with a ratio 2.2: 1 hempcrete has a higher density compared with hempcrete than filler-only hemp shives. The results of the compressive strength testing have shown when flax shives were added to the mixture the strength significantly increased. Then part of the quicklime was replaced by cement (10%) the strength was slightly increased in hempcrete with hemp shives and drastically decreased the compressive strength than filler hemp and flax shives.

The results of the thermal conductivity test show that hempcrete with a higher proportion of binder by weight has the highest conductivity, but that concretes with a sapropel admixture have a lower thermal conductivity. The mixtures prepared using binders and filler (hemp and flax shives) have higher conductivity compared with hempcrete than filler-only hemp shives.

Keywords: hempcrete, mechanical properties, thermal conductivity

Introduction

In the construction sector, it is important to develop building materials that comply with the principles of sustainable construction, i.e. the use of renewable raw materials and the development of the most energy-efficient materials and composites. Table 1 shows the mechanical properties of different types of potential natural fibres for composite applications.

Table 1. Mechanical properties of different types of potential natural fibres for composite applications [1]

	Tensile strength (MPa)	Elongation at break (%)	Young modulus (GPa)
Natural fibres			
Flax	300–1500	1.3–10	24–80
Jute	200–800	1.16–8	10–55
Sisal	80–840	2–25	9–38
Kenaf	295–1191	3.5	2.86
Pineapple	170–1627	2.4	60-82
Banana	529–914	3	27–32
Coir	106–175	14.21–49	4–6
Oil palm (empty fruit)	130–248	9.7–14	3.58
Oil palm (fruit)	80	17	
Ramie	348–938	1.2–8	44–128
Hemp	310–900	1.6–6	30–70
Wool	120–174	25–35	2.3–3.4
Spider silk	875–972	17–18	11–13
Cotton	264–800	3–8	5–12.6

Fibre hemp shives have a porous microstructure which is suitable for the production of efficient thermal insulation or thermal insulation-structural materials [2]. The physical-mechanical properties and structure of fiber hemp shives and their composites with inorganic, organic, and other binders are as well reviewed in scientific works [3]. Balčiūnas et al. [4] formed and investigated composites made of hemp shives and different binding materials (cement, lime, clay, starch). The composite with cement as a binding agent had the best strength properties. Mix design, casting process, and mechanical behavior described in [5]. Parcesepe et al, 2021 [6] assessed the mechanical and thermal properties of hemp-lime mortar.

The aim - to investigate the changes in mechanical and thermal properties of hempcrete by adding flax shives.

Testing methodology

We used the methodology described in our previous research [7]

Binders used in the preparation of the hempcrete mixture: quicklime, portland cement CEM II / A LL – 42.5N, organic sapropel. Hemp and flax shives aggregates were used for hempcrete. Drinking water was used to form the hempcrete mixture. For the testing of hempcrete, three compositions (HF) of mixtures were prepared using binders and filler (hemp and flax shives) ratio 2.2: 1, and research results were compared with our previous research without flax shives [7] (Table 1).

Table 1. Compositions of hempcrete mixtures

No. of mixture	Amount of binder, %	Materials
HF1	2.2:1	2.2 parts by weight of quicklime (100%), 1 part hemp and 1 part flax shives
LB1 [7]	2.2:1	2.2 parts by weight of quicklime (100%), one part hemp shives
HF2	2.2:1	2.2 parts by weight of quicklime (90%) and cement (10%), 1 part hemp, and 1 part flax shives
LB2 [7]	2.2:1	2.2 parts by weight of quicklime (90%) and cement (10%), one part hemp shives
HF3	2.2:1	2.2 parts by weight of quicklime (90%) and organic sapropel (10%), 1 part hemp, and 1 part flax shives
LB3 [7]	2.2:1	2.2 parts by weight of quicklime (90%) and organic sapropel (10%), one part hemp shives

Quicklime was used as the main binder. The amount of water evaporated was weighed and compensated. Part of the mixtures were produced using a mixture of binders in which 10% of lime has been replaced by cement (CEM II / A – LL 42.5 N) or organic sapropel (using calculations of the dry weight). Mixtures are prepared by forced mixing in a blender.

The bulk densities of the materials used to prepare the hemp concrete mixture were determined and presented in Table 2. Bulk density was determined according to the standard [8].

Table 2. Bulk densities (bulk weights) of materials used in the manufacture of hempcrete

Materials	Bulk density (volumetric weight) kg / m^3	
	freely poured	compressed by hand
Calcite quicklime	510	-
Cement CEM II / A – LL 42.5 N	1230	-
Hemp shives	113	136
Flax shives	91	135

To evaluate the water content of sapropel, its moisture content was determined by the drying method. Moisture by mass was calculated according to the formula:

$$w_m = \frac{m_w}{m_d} \cdot 100 = \frac{m_{wt} - m_d}{m_d} \cdot 100\% = \frac{100{,}0 - 12{,}0}{12} \cdot 100 = 733{,}3\% \quad (1)$$

where m_w – the mass of water in the material, m_d –the mass of dry content, m_{wt} – the mass of wet content.

These tests show that in sapropel the main part of the mass is water and the dry content is only 12 % of wet sapropel weight.

When mixing quicklime with sapropel, its content was calculated based on dry content, therefore, the amount of water in the mixture was reduced by the amount of water in sapropel. The water content was calculated according to the formula:

$$V = 1{,}5 \cdot m_{sh} + 0{,}92 \cdot m_q + 0{,}32 \cdot m_c + 0{,}32 \cdot m_s \quad (2)$$

where m_{sh} – is the mass of the shives, m_q – is the mass of quicklime, m_c – the mass of the cement, m_s – the mass of the dry sapropel.

Specimens (cubes of 10 × 10 × 10 cm) for the determination of the density and compressive strength were made from 3 composition mixtures. Tile-shaped boards (20 × 20 × (4 ... 5) cm) were made for the determination of the conductivity coefficient. The mixture was poured into the mold and compacted by hand using a wooden rod with a cross-sectional dimension of 4 × 4 cm. Specimens were removed from the molds after 1-2 days. Under laboratory conditions for one month, hardened specimens were weighed on electronically electronic scales to determine their dimensions. The density of the specimens was determined according to the standard [9].

Mechanical properties, in particular strength, are important for the evaluation of essential requirements of mechanical strength and stability in lime-hemp concrete structures. Compressive strength is determined by standard methodology [10,11] testing the specimens by a mechanical test machine to 10% deformation. The direction of compression was parallel to the direction of formation.

The thermal conductivity coefficient was determined using the heat flow meter LaserComp FOX according to the standard [12].

Results

The early obtained results [7] from research on hempcrete made with three compositions of mixtures prepared using binders and filler (hemp shives) ratio 2.2: 1 have shown 459 ... 497 kg / m^3 density. Concrete made with aggregates made from a mixture of hemp and flax shives has a higher density (497…564 kg / m^3), as the flax is finer and fills the spaces between the hemp shives. Hempcrete made with a mixture of 90% quicklime and 10% cement (LB2) has a higher density (497 kg / m^3) compared to the mixture (LB1=482 kg / m^3). Hempcrete made with 10% sapropel mixture has a lower density (LB3=459 kg / m^3 and HF3=497 kg / m^3).

The results of the compressive strength testing have shown - that hempcrete made with quicklime binder (LB1) has a compressive strength is 693 kPa. Then flax shives were added to the mixture (HF1) the strength is significantly increased to 929 kPa. For hempcrete made with quicklime and 10% cement binder (LB2), the strength is slightly increased and is 698 kPa, higher than hempcrete made with hemp and flax shives (HF2=689 kPa). A decrease in strength is observed in hempcrete made with 2.2 parts by weight of quicklime (90%) and organic sapropel (10%), one part hemp shives (LB3) or with hemp and flax shives (HF3). In this case, the compressive strength of the concrete is LB3=572 kPa or HF3=612 kPa. A graphical representation of the density and compressive strength of air-dried hempcrete when the filler is hemp shives and when the filler is hemp and flax shives is given in Figure 1.

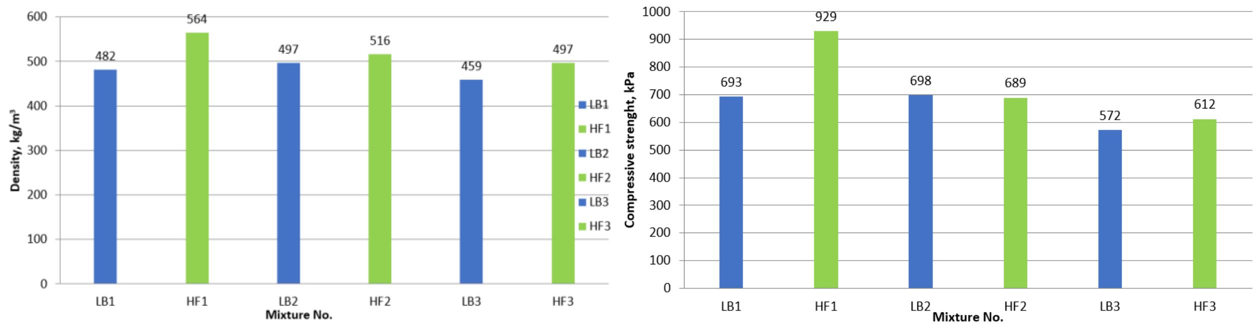

Figure 1. Density and compressive strength of air-dried hempcrete (blue color- the filler is hemp shives [7], green color - the filler is hemp and flax shives)

The correlation between hempcrete density and compressive strength was established. The diagram (Figure 2) illustrates a consistent association between hempcrete density and compressive strength: higher concrete density corresponds to increased strength.

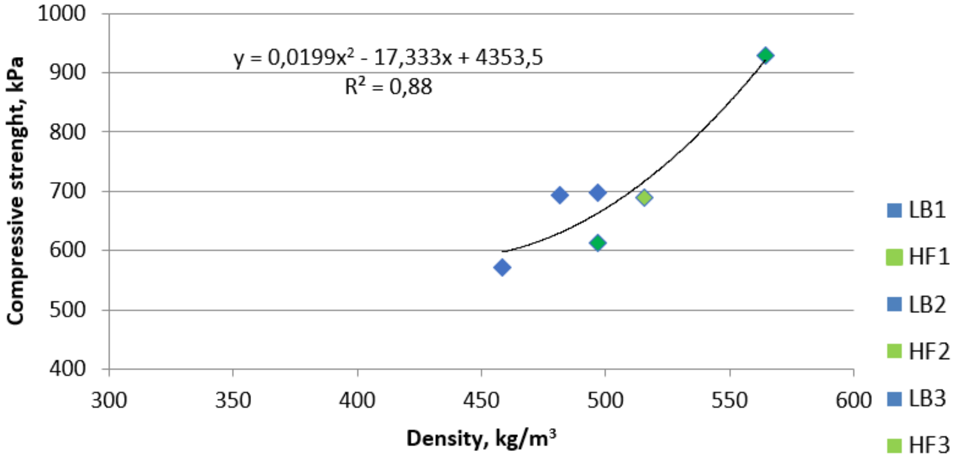

Figure 2. Relationship between the density and compressive strength of hempcrete

The thermal conductivity of hempcrete was investigated by analyzing its properties. The findings from the thermal conductivity study indicate that hempcrete using mineral binders exhibits the highest conductivity. Conversely, hempcrete utilizing a sapropel-organic binder demonstrates lower thermal conductivity, as shown in Table 3.

Table 3. Thermal conductivity of air-dried hempcrete

Hempcrete composition No. (ratio of binders to aggregates see Table 1)	Thermal conductivity of air-dry samples, W / (m · K)
LB1 (2.2:1) [7]	0.114
HF1 (2.2:1)	0.115
LB2 (2.2:1) [7]	0.108
HF2 (2.2:1)	0.111
LB3 (2.2:1) [7]	0.096
HF3 (2.2:1)	0.091

The connections between thermal conductivity and compressive strength, density, and thermal conductivity were established and depicted in Figure 3.

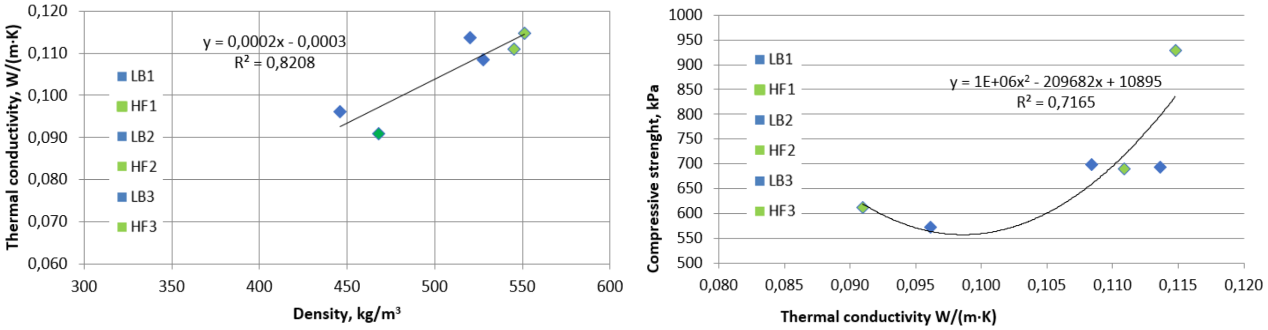

Figure 3. Relationships between thermal conductivity - density and compressive strength of hempcrete

The graphs and equations presented in Figure 3 demonstrate consistent relationships between thermal conductivity and compressive strength, as well as between density and thermal conductivity. Specifically, the data shows that as compressive strength increases, thermal conductivity also increases.

Conclusions and recommendations

1. Research of lime-hemp concrete has shown - that for the mixtures prepared using binders and filler (hemp and flax shives) with a ratio 2.2: 1 hempcrete has a higher density (497…564 kg / m^3) compared with hempcrete then filler only hemp shives (459 ... 497 kg / m^3) as the flax are finer and fills the spaces between the hemp shives.
2. The results of the compressive strength testing have shown - that hempcrete made with quicklime binder has a compressive strength is 693 kPa. Then flax shives were added to the mixture the strength significantly increased to 929 kPa. Then part of the quicklime was replaced by cement (10%) the strength is slightly increased in hempcrete with hemp shives and is 698 kPa, which is higher than in hempcrete made with hemp and flax shives (689 kPa). It was found, that the replacement of 10% quicklime by cement increases the compressive strength of 698 kPa (hemp shives) and drastically decreases the compressive strength from 929 kPa to 689 kPa (hemp and flax shives). The compressive strength testing results show that organic sapropel-containing hempcrete is weaker than hempcrete made with mineral binders.
3. The results of the thermal conductivity test show that hempcrete with a higher proportion of binder by weight has the highest conductivity, but that concretes with a sapropel admixture have a lower thermal conductivity. The mixtures prepared using binders and filler (hemp and flax shives) have higher conductivity compared with hempcrete than filler-only hemp shives.

REFERENCES

1. Cheung, H. Y., Ho, M. P., Lau, K. T., Cardona, F., & Hui, D. Natural fibre-reinforced composites for bioengineering and environmental engineering applications. *Composites Part B: Engineering*, *40*(7), 2009. P. 655-663.

2. Balčiūnas, G. Investigation of building composites with fibre hemp shives. Doctoral dissertation. Vilnius Gediminas Technical University, 2015. 101 p.

3. Kremensas A. Development and research of building biocomposite board from fibre hemp shives. Doctoral dissertation. Vilnius: Technika, 2018. 140 p.

4. Balčiūnas G., Vėjelis S., Vaitkus S., Kairytė A. Physical Properties and Structure of Composite Made by Using Hemp Hurds and Different Binding Materials. Procedia Engineering, Vol. 57. 2013. p. 159–66 https://doi.org/10.1016/j.proeng.2013.04.023.

5. Tronet P., Lecompte T., Picandet V., Baley Ch. Study of lime hemp concrete (LHC) - Mix design, casting process and mechanical behavior. Cement and Concrete Composites 67, 2016, p. 60-72. http://dx.doi.org/10.1016/j.cemconcomp.2015.12.004.

6. Parcesepe, E.; De Masi, R.F.; Lima, C.; Mauro, G.M.; Pecce, M.R.; Maddaloni, G. Assessment of Mechanical and Thermal Properties of Hemp-Lime Mortar. Materials 2021, 14, 882. https://doi.org/10.3390/ma14040882

7. Gurskis V. Mechanical properties and thermal conductivity of lime–hemp concrete [Electronic resource] / V. Gurskis, R. Šadzevičius, D. Ramukevičius // Матеріали L науково-технічної конференції підрозділів ВНТУ, Вінниця, 10-12 березня 2021 р. – Електрон. текст. дані. – 2021. – Режим доступу: https://conferences.vntu.edu.ua/index.php/all-fbtegp/all-fbtegp-2021/paper/view/12640.

8. EN 1097-3: 2002.Tests for mechanical and physical properties of aggregates. Part 3: Determination of loose bulk density and voids.

9. EN 12390-7: 2009Testing hardened concrete - Part 7: Density of hardened concrete.

10. EN 12390-3: 2009.Testing fresh concrete - Part 3: Vebe test

11. EN 826:2013.Thermal insulating products for building applications – determination of compression behaviour.

12. EN 12667:2002. Thermal performance of building materials and products – determination of thermal resistance by means of guarded hot plate and heat flow meter methods – products of high and medium thermal resistance.

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