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MECHANICAL PROPERTIES AND THERMAL CONDUCTIVITY OF LIME–HEMP CONCRETE

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Abstract

The mechanical and thermal properties of lime-hemp concrete (hempcrete) were analysed in the paper. For the testing of hempcrete, three compositions of mixtures were prepared using binders and filler (hemp shives) ratio 2.2: 1. Quicklime was used as the main binder. Part of the mixtures were produced using a mixture of binders in which 10% of lime has been replaced by cement or organic sapropel. The research results have shown 459 ... 497 kg / m^3 density of hempcrete. Hempcrete made with a mixture 10% cement has a higher density, with 10% sapropel - a lower density. The compressive strength testing results shows that organic sapropel-containing hempcrete is weaker than made with mineral binders. The results of the thermal conductivity research shows that the hempcrete with the mineral binders has the highest thermal conductivity, with sapropel - a lower thermal conductivity.

Keywords: hempcrete, mechanical properties, thermal conductivity

Introduction

Environmentally friendly construction is gaining popularity in the world - it is a set of construction methods of buildings and engineering structures that are maximally compatible with nature and social environment. The basis of this construction is the use of low-energy building materials for the construction of buildings. Most plant-based products, including fibrous hemp products, meet these requirements [1]. Scientific literature presents researches of composites produced from hemp shives aggregate which are bound with various binders (lime, cement, their mixtures, various resins, plaster, organic binders, etc.) or using self-binding technology [2]. Lime-Hemp Concrete (LHC) or Hempcrete - material is comprised of a mineral binder, often a combination of hydraulic and non- hydraulic lime, with a plant-based aggregate, mostly consisting of shiv with or without small residual fibers [3].

Construction law requires, the structure (or part of it) must be designed and constructed from such construction products, the properties of which during the economically reasonable period of use of the structure would ensure the following essential requirements of the structure [4]:

1) mechanical strength and stability;
2) fire safety;
3) hygiene, health and environmental protection;
4) safety of use;
6) energy saving and heat preservation ,
7) sustainable use of natural resources

Main characteristics of these essential requirements according to European standards are determined using normative documents [5-9].

The aim - to investigate the influence of binders with various composition on the mechanical and thermal properties of lime-hemp concrete (here in after - hempcrete).

Testing methodology

Binders used in the preparation of the hempcrete mixture: quicklime, portland cement CEM II / A LL – 42.5N, organic sapropel. Hemp shives aggregates were used for lime-hemp concrete. Drinking water was used to form the hempcrete mixture. For the testing of hempcrete, three compositions of mixtures were prepared using binders and filler (hemp shives) ratio 2.2: 1 (Table 1).

Table 1. Compositions of hempcrete mixtures

No. of mixture	Amount of binder, %	Materials
LB1	2.2:1	2.2 parts by weight of quicklime (100%), one part hemp shives
LB2	2.2:1	2.2 parts by weight of quicklime (90%) and cement (10%), one part hemp shives
LB3	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 [9].

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

In order 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:

$$w_m = \frac{m_v}{m_s} \cdot 100 = \frac{m_d - m_s}{m_s} \cdot 100\% \; = \frac{100{,}0 - 12{,}0}{12} \cdot 100 = 733{,}3\% \tag{1}$$

where m_v – the mass of water in the material, m_s –the mass of dry content, m_d – 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 on the basis of dry content, therefore, the amount of water in mixture was reduced by the amount of water in sapropel. The water content was calculated according to formula:

$$V = 1{,}5 \cdot m_{sp} + 0{,}92 \cdot m_k + 0{,}32 \cdot m_c + 0{,}32 \cdot m_s \tag{2}$$

where m_{sp} – the mass of the lime, m_k – 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 compositions mixtures. Tile-shaped boards (20 × 20 × (4 ... 5) cm) were made for the determination of the conductivity coefficient. The mixture was poured into the mould and compacted by hand using a wooden rod with a cross-sectional dimension of 4 × 4 cm. Specimens were removed from the moulds 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 [10].

Mechanical properties, in particular strength, are important for the evaluation essential requirement of mechanical strength and stability in lime-hemp concrete structures. Compressive strength determined by standard methodology [4,11] testing the specimens by a mechanical test machine to 10% deformation. The direction of compression was parallel to direction of formation.

The thermal conductivity coefficient was determined using the heat flow meter LaserComp FOX according to the standard [8].

Results

The obtained results from research of 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. Hempcrete made with a mixture of 90% quicklime and 10% cement has a higher density (497 kg / m^3). Hempcrete made with 10% sapropel mixture has a lower density (459 kg / m^3).

The results of the compressive strength testing have shown - hempcrete made with quicklime binder the compressive strength is 693 kPa. For hempcrete made with quicklime and 10% cement binder the strength is slightly increased and is 698 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. In this case, the compressive strength of the concrete is 572 kPa. A graphical representation of the density and compressive strength of air-dried hempcrete is given in Figure 1. The presented results shows, the compressive strength of hemcrete is less than 2 MPa, the same results are obtained by another researchers [3].

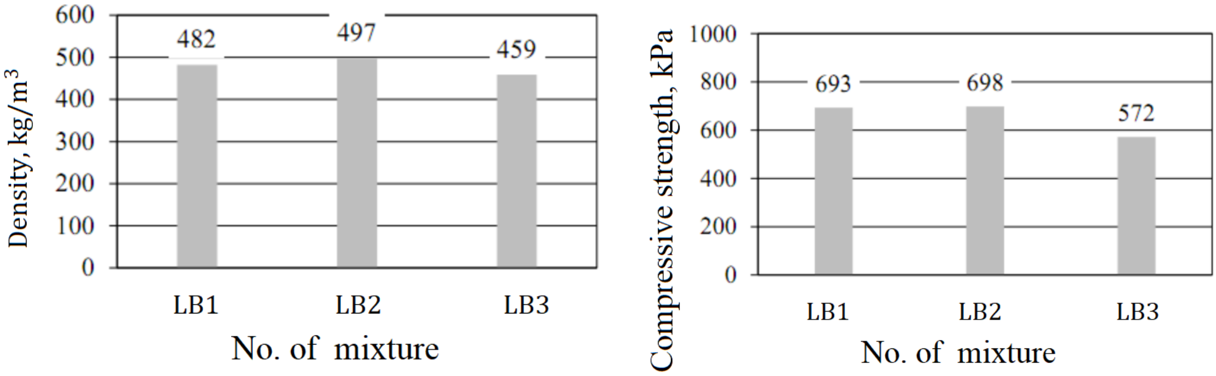

Figure 1. Density and compressive strength of air-dried hempcrete

The relationship between hempcrete density and compressive strength was determined. The graph (Figure 2) shows that there is reliable relationship between hempcrete density and compressive strength: as the density of the concrete increases, the strength increases.

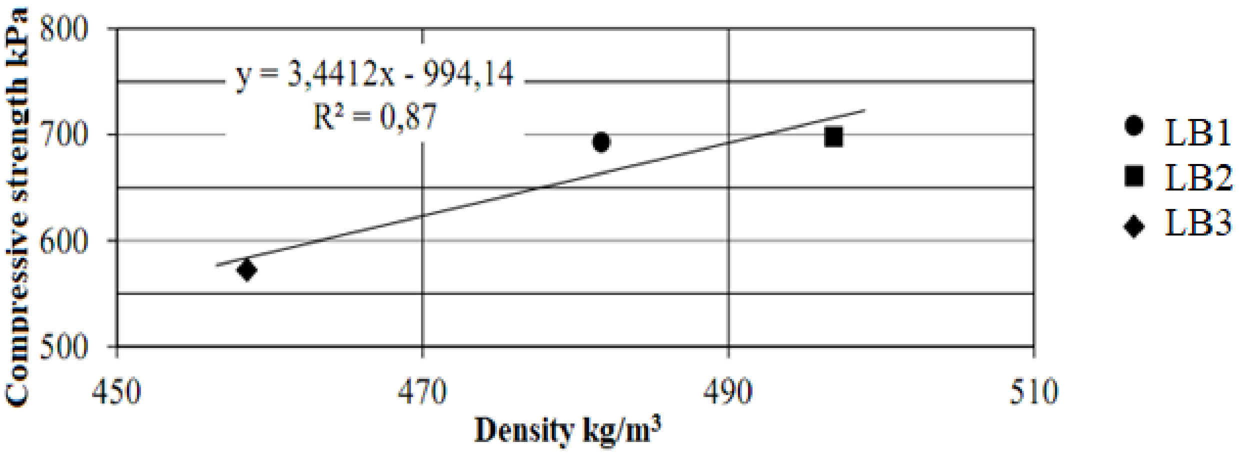

Figure 2. Relationship between the density and compressive strength of hempcrete

The thermal conductivity was determined by studying the properties of hempcrete. The results of the thermal conductivity study show that hempcrete with mineral binders have the highest conductivity. Hempcrete with sapropel - organic origin binder has lower thermal conductivity (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)	0.114
LB2 (2.2:1)	0.108
LB3 (2.2:1)	0.096

The relationships between the thermal conductivity and the compressive strength, density and thermal conductivity were constructed (Fig.3).

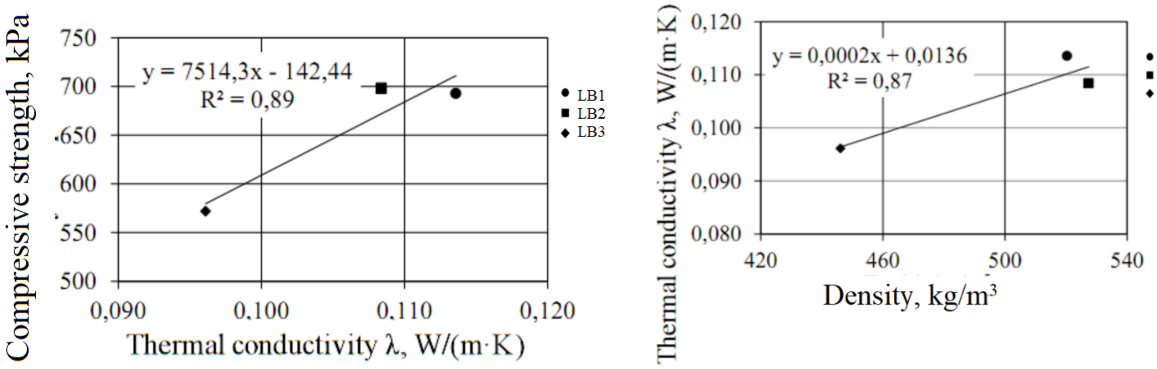

Figure 3. Relationships between thermal conductivity - density and compressive strength of hempcrete

The graphs and equations in Fig. 3 shows that there are reliable relationships between the thermal conductivity and compressive strength, the density and thermal conductivity, i. e. with increasing compressive strength, thermal conductivity increases.

Conclusions and recommendations

1. Research of lime-hemp concrete have shown - for the mixtures prepared using binders and filler (hemp shives) with ratio 2.2: 1 hempcrete has density 459 ... 497 kg / m^3, compressive strength - 572 ... 693 kPa and thermal conductivity - 0.096 ... 0.114 W / (m · K).
2. The compressive strength testing results shows that organic sapropel-containing hempcrete is weaker than hempcrete made with mineral binders. It was founded, that the replacement of 10% quicklime by cement or sapropel has a compressive strength of 698 kPa and 572 kPa, respectively.
3. The results of the thermal conductivity investigations shows that the hempcrete with the mineral binders has the highest thermal conductivity, and hempcrete with sapropel binder has a lower thermal conductivity.

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