

Experimental justification for sapropel and hemp shives use as a thermal insulation in Latvia

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Abstract. Fossil energy resources in Latvia are imported from other countries, but at the same time, our country is rich in renewable energy resources and other raw materials, which are used very little. In the study it is proposed to create a thermal insulation material from hemp shives grown in Latvia as a filler material and lake sediment - sapropel as a binding agent. Both of the following materials are organic, renewable and locally available. Laboratory experiments show that ecological and complying with modern requirements thermal insulation material can be obtained from local, renewable raw materials: sapropel and hemp shives.

Keywords: sapropel, hemp shives, thermal insulation construction material.

I INTRODUCTION

Latvian National Saeima accepted Latvian National Development Plan until 2020, which emphasizes the improvement of energy efficiency in all economic spheres. Great energy savings can be achieved in the construction sector by improving the energy efficiency of buildings by reducing energy consumption in construction output and simultaneously switching to renewable energy sources. [1]

In Latvia fossil energy resources are imported from other countries, but at the same time, our country is rich in renewable energy resources and other raw materials, which are used very little.

Renewable materials which contains natural fibers (e.g. jute, flax, hemp, cotton, cellulose) have many positive features: low thermal conductivity, low density, good specific tensile strength.[2,3,4] The natural fiber materials also have a low impact on the environment.[2,5]

In the study it is proposed to create a thermal insulation material from the hemp shives grown in Latvia as a filler material and lake sediment - sapropel as a binding agent. Both of the following materials are organic, renewable and domestic.

The industrial hemp (*Cannabis sativa*) has been positively regarded by its good thermal insulation and mechanical properties. Hemp stalk grows in 3.5 months and absorbs 4-5 times more CO₂ than a growing forest.[6,7]

Light-weight hemp concrete (hemp shives, lime and water) are used for filling the walls, floors and roof as

thermal insulation material.[8] Scientific literature has examined hemp concrete's thermal, physical, mechanical properties and moisture transfer as well as its use in construction. [9, 10, 11]

Hydraulic lime is commonly used as binding agent in hemp concrete. This research offers to use hemp shives in combination with organic binder agent derived from lake silt - sapropel.

Sapropel supplies are commonly found worldwide. It is a renewable resource. The most intense sapropel formation and accumulation is typical in Asian and European temperate climate zones (Russia, Scandinavian Peninsula, France, Germany, Poland, the Baltic States, Belarus and Ukraine) and in the North American continent in the Great Lakes region (Canada and United States).[12-17] Sapropel supplies and their chemical composition have been studied in several lakes in Russia. [18, 19] Significant sapropel supplies are also found in the Mediterranean. [20]

The first industrial use of hemp and hemp-lime composites as building insulation material in France took place in 1980s. [21] According to the Latvian National Development Plan creating a new composite material from local, renewable resources is actual task nowadays.

The objective of this study is to create a new constructive and insulation material from sapropel and hemp shives. The new construction material can be used as thermal insulation material in new building construction and to improve energy efficiency of old buildings.

II MATERIALS

Sapropel

The first studies of sapropel in Latvia started in the 1950's. This was carried out in the Latvian SSR Academy of Sciences, Institute of Chemistry and later in the Institute of Forestry Problems led by N.Brakse, B.Vimba and A.Kalnina. In the studies chemical composition and use of sapropel was found out. [22]

Sapropel are organogenetic lake sediments, which are derived from debris of aquatic plants and aquatic animals, which mixed with mineral particles (sand, clay, calcium carbonate and other compounds). It is mucilaginous jelly-like mass of colloidal structure with following undertones - brownish, black, gray, greenish or yellowish, which occurs in the majority of Latvian lakes and in more than third of the Latvian swamps.

Sapropel deposits thickness range from a few centimeters to about 20 m. [23]

Sapropel characterizing parameters are ash content, moisture, organic matter, as well as contents of iron and calcium. Ash content is characterized by mineral admixture quantity, which can vary in very large ranges from 5 to 85%. Natural moisture of sapropel ranges from 70 to 98%. Biological structure characterize organisms from which sapropel is formed. [23]

Total 1327 such lakes can be found in Latvia. As a result of work, an information was obtained on the lake sapropel deposits, which is summarized in the passports of findings. Forecasts stocks are laid down for each sapropel finding. Search works allow to select sapropel finding place by volume of stocks and by certain raw materials which have useful qualitative indicators for the further research which are needed before the industrial extraction of mineral resources. [23]

Predominantly studies of sapropel so far are related to the use in agriculture (as fertilizer), medicine (such as therapeutic mud) and chemical-technological processes (as fuel). The goal of this study is to look at the sapropel as construction material and especially, as a binder agent of sapropel-hemp shives insulation board and its production.

Hemp shives

In production of sapropel and hemp shives insulation board it is intended to use residues (hemp shives) resulting from the processing of hemp. In hemp stalks about sixty-five percent are woody hemp part or the hemp shives which are not fully used. [24]

Hemp is an ancient crop, it has many and different use. Cultivation of hemp in Latvia has a very long history - the oldest hemp seeds were found in Talsu castle hill layers of 11-13th century, but it is likely that they might be cultivated already earlier. [25]

In Latvia from 2008 it is allowed to grow *Cannabis sativa* seed and to obtain the fiber. Consequently now hemp is cultivated in several Latvian regions

approximately in 600 ha, main products are fiber and seed.

According to the data of the Association of industrial hemp in 2013 in the European Union were grown approximately 14 000 ha of hemp. [26]

European Union Regulation of the common agricultural policy (CAP), for time period 2014- 2020 hemp is included in section on environment-enhancing factors. In addition, 1 ha of hemp each year absorbs four times more CO₂ than the same area of forest.

Hemp shives in practice are used as a raw material for building materials, animal bedding, gardening, firewood briquettes, in production of hemp panels and granule or in production of thermal insulation materials. [27]

In 2010 the total quantity of hemp shives was 44 000 t. In percentage distribution of the 44 000 tonnes of hemp shives 62% was used for animal bedding, 45% of them used in the horse stables. 15% of hemp shives were used in the construction area, namely in hemp shives and lime mixtures. Hemp shives lime lightweight concrete is cast in wooden frame during the construction of buildings, such an approach has been used for a couple of years for construction of private houses in France, UK and Ireland.[28] The European Eco-builders looks at this new product with great ambition for use it in ecological constructions.

The remaining 22% of hemp shives are used in many different places elsewhere, such as in cogeneration stations to generate heat / electricity, a small amount in particle board production and in other small productions.

Laboratory experiments show that from local, renewable raw materials; sapropel and hemp shives can be obtained high-quality, ecological and complying to modern requirements thermal insulation construction material.

For scientific studies natural raw materials were derived from a various local companies. Sapropel was extracted from the Ubogovas lake in Makonkalna parish, Rezeknes district. In turn hemp shives from "Latgale Agricultural Science Centre" Dr.agr. V. Stramkale, by processing them in Preiļu pretreatment workshop. In G. Liberta Innovative microscopy center of Daugavpils University collected sapropel samples with an electronic microscope VEGA were tested. Obtained results are summarized in Table I, where min and max measurements are % from weight.

Sapropel mass obtained from lake was 5.66% sapropel and 94.34% water. Shives with two different sizes were taken – one with large fraction of long and mechanically unbroken shives (L) and one with smaller fraction which has gone more processing cycles (S). Composition, density and thermal conductivity is visible in Table II.

Table I
SAPROPEL CHEMICAL ELEMENT MIN AND MAX VALUES% BY WEIGHT

Chemical elements	C	O	Mg	Al	Si	S	K	Ca	Fe	Mo
Max	89,53	31,18	0,66	1,88	3,29	0,39	1,35	2,67	1,27	0,49
Min	53,06	35,40	0,66	1,55	2,86	0,40	0,52	1,07	0,94	0,49

TABLE II
SIZE AND MECHANICAL PROPERTIES OF HEMP SHIVES

Name	Fibre	>20mm	10-20mm	0,63-10mm	Dust	Density, kg/m ³	Thermal cond. W/m*K	Moisture, %
L	2,1%	16,9%	29,6%	48,3%	3,1%	62,53	0,051	9,72%
S	1,5%	4,9%	25,7%	65,3%	2,6%	78,43	0,053	8,96%

TABLE III
COMPOSITIONS OF MIXTURES

	Shives type	Shives, g	Sapropel, g	Water, g	Sapropel: water ratio
L1	L	3673,6	5510,4	5510,4	1:1
S1	S	3149,2	4723,8	4723,8	1:1
S2	S	2830	5660	2830	2:1
S3	S	2237	6100	610	10:1

III METHODS

A. Mould preparation

For the tests a moisture resistant plywood moulds were used, they are made of 28 mm thick plywood to withstand the applied pressure which is applied using four 10 mm diameter threaded rods at each corner of the mould. To ensure that the material doesn't stick to the mould, it is greased with formwork oil.

B. Preparation of ingredients

Before the mixing process all ingredients were prepared for the test. The hemp shives were weighted – the used amounts are shown in Table III. The ratio between shives and binder is 1:3 by mass, binder mass is sapropel with additional water. In the first part of the test - to ensure that sapropel fully mixes with the shives it is diluted with water to make it more workable, sapropel/water ratio 1:1 for L1 and S1 samples. The water is added to sapropel and then it is mixed together using electrical hand mixer.

In the second part of the test different sapropel/water ratio were taken to test the effect of additional binder addition on mechanical properties of the material. Binder/shives ratio wasn't changed,

water/sapropel ratio was 1:2 for S2 sample and 1:10 for S3 sample.

A. Mixing

Mixing was done using drum type concrete mixer, speed 22 rpm. First, the shives were placed in a working mixer, shortly after the binder mixture was poured in. The mixing process was continued for 3 minutes. No lumps formed in the mixing process, which is a difference from hemp-lime mixtures when prepared in drum mixer, that could be attributed to slightly wetter mix that of hemp-lime samples.

B. Moulding

For the first part of the test the moulding is done in three stages. First the mould with threaded rods is filled with the raw material to the top – 10 cm, then the pressure plate is put on and by tightening the nuts the sample is pressed from 10 cm thickness to 6 cm (Fig.1). Filing of the moulds is done in 4 to 5 cm layers by slightly tamping every layer. Samples are marked with letter P.

Second and another mould is filled with material until the 8 cm mark, a plywood plate is put on a top and concrete blocks with total weight of 50 kg, which makes the sample to shrink to around 6 cm in height. Samples are marked with letter K.

Third mould is filled with remaining material by filling in layers and tamping, a plywood plate is put on top, but no extra pressure is added. For the second part of the test only first two stages are used, as samples without any pressure showed poor results.



Fig. 1. Mould for compression

C. Demoulding

Demoulding of the samples were done after two days of curing, they were demoulded and left to cure in horizontal positions for one more day. After that they were put in a vertical position and left to cure in laboratory conditions (20 ± 2 °C and 40 ± 10 %RH). The weight of the samples were regularly checked to see if any changes occurs in mass, to assess the completeness of drying. The longest time necessary for complete drying was for sample S2P as it is the sample with the highest density.

D. Testing

The testing was done in two stages, First, after the complete drying, sample dimensions and weight were measured, then – thermal conductivity. It was measured with a use of LaserComp FOX600 heat flow meter, following guidelines of LVS EN 12667, test settings 0 °C upper and 20 °C lower plate. After this test the samples were sawn into pieces for mechanical testing – two for compressive strength parallel to compaction direction, two for compressive strength crosswise the compaction direction and one for flexural strength. Dimensions – $100 \times 100 \times$ height mm for compressive tests and $350 \times 100 \times$ height for compressive strength. A layer of gypsum is spread over the interfaces to ensure even pressure application.

Tests were done according to LVS EN 826 on Zwick Z100 universal testing machine, with the pressure applied at 5mm/min, in the process a force-deformation diagram is recorded. The compressive strength test result is a value of pressure applied at 10% relative vertical deformations. Flexural test is continued until rupture, span between points – 200 mm, a 3 N prepressure is applied to the samples.

IV RESULTS AND DISCUSSION

The summary of the test results can be seen in the Table IV. The type of mixture according to Table III is appended with corresponding type of compression during the moulding phase – P, K or N.

From the table it can be seen that compression during the preparation have direct impact on density, as P samples were pressed by 40% of height, K for 25% and N for 0%. But the differences in densities from the table doesn't match the differences of compaction, this is due to the fact, that all samples were slightly tamped during moulding and mixing of the material also made it to become more dense, so the effect of additional compression of the samples were not so great.

Densities also differed because of the sapropel/water ratio, as the hemp/binder ratio wasn't changed. Although the ratio differs 10 times for some samples, the density fluctuation is not so great. This is due to the fact that sapropel initially contained more than 95% water which, and by changing the ratio from 1:1 to 10:1 changes the amount of sapropel only less than two times, because the shives: binder ratio didn't change.

From the table it can also be seen that density have impact on thermal conductivity. This is because shives and sapropel have higher thermal conductivity than that of still air inclusions in thermal insulation materials, which means that by decreasing the amount of this air with addition of more sapropel and shives to volume, the thermal conductivity also gets higher. The correlation between density and thermal conductivity can be seen in Fig. 2.

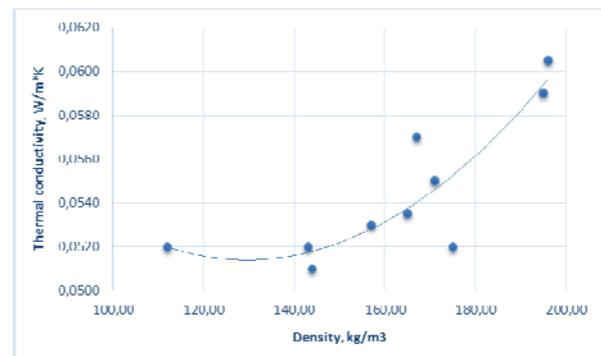


Fig.2. Thermal conductivity/density graph

This previous effect of increased density on thermal conductivity doesn't work on samples made without any pressure. This could indicate that when making samples with no pressure applied during curing the hemp shives are too far away from each other and doesn't create concealed volumes, which allows air to move more freely around and that makes the thermal conductivity of the samples to be higher. Because of

this effect, samples with no pressure applied weren't made in second part of the test.

From the results an effect of different shives on end properties of the material also can be seen. Large shives (L) shows slightly better thermal conductivity, which can be explained by more long and undamaged fiber tubes which has shown lower thermal conductivity than smaller, more processed fiber [29].

But mechanical properties of these long shives are worse, samples for compressive strength crosswise failed while they were sawn, compressive strength is even three times lower, the same for flexural strength. This could be explained by contact zone between the shives which is less for the long shives, this could attribute for the lower mechanical strength.

TABLE IV
TEST RESULTS

Type	Sapropel: water ratio	Density, kg/m ³	Thermal cond., W/m*K	Compr. strength, MPa	Compr. Strength crosswise, MPa	Flex. strength, MPa
L1P	1:1	165,00	0,0535	0,046	x	0,012
L1K	1:1	144,00	0,0510	0,019	x	0,007
L1N	1:1	112,00	0,0520	0,016	x	x
S1P	1:1	171,00	0,0550	0,089	0,027	0,022
S1K	1:1	157,00	0,0530	0,072	0,029	0,022
S1N	1:1	143,00	0,0520	0,033	0,011	x
S2P	2:1	196,00	0,0605	0,113	0,034	0,021
S2K	2:1	175,00	0,0520	0,094	0,015	0,015
S3P	10:1	195,00	0,0590	0,148	0,042	0,031
S3K	10:1	167,00	0,0570	0,087	0,025	0,016

The results also shows a correlation between density and mechanical strength – if the material is more dense then it also have greater mechanical strength. From the table it can be seen that the method how the density is raised isn't important, as both – with addition of more sapropel or with additional compression – achieves similar results, which also indicate that the mechanical strength is dependant on contact zone. Graphical correlation between compressive strength and density can be seen in Fig.3.

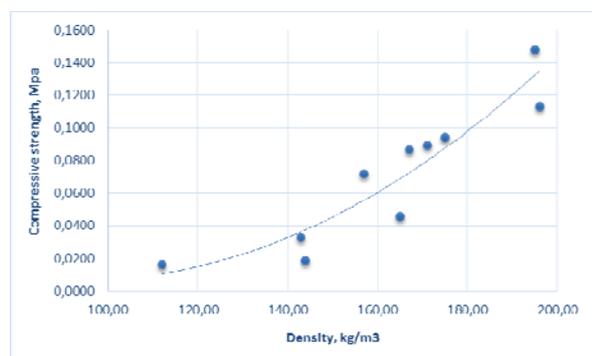


Fig.3. Compressive strength/density graph

If the results are compared to similar studies, then it can be seen that achieved thermal conductivity is adequate for sapropel thermal insulation materials as it is around 0,053 W/m*K [30],[31]. But if compared to

other hemp materials, for example, a hemp lime concrete, then it has superior thermal conductivity as hemp-lime materials have it around 0,075 W/m*K [32], although their mass is also larger.

Regarding the mechanical strength – the achieved result is equal to results from similarly made sapropel insulation material – around 0,15 MPa for compressive strength and 0,03 for flexural strength [31], but inferior to hemp-lime whose compressive strength is around 0,25 MPa, or sapropel insulation materials made with higher pressure and under temperature treatment, which activates natural binders in sapropel and hemp shives, with his method compressive strength from 0,35 to 1,85 MPa is achievable, without significant thermal conductivity losses.

V CONCLUSIONS

1. Use of longer shives improves thermal conductivity because of more undamaged fiber, but worsens mechanical properties because of less contact zone between shives.
2. Samples should be compressed during the curing to ensure more closed air spaces between the shives, without compression thermal conductivity rises.
3. Density influences thermal conductivity of the material as well as mechanical strength, but is not important how the density is increased – with more binder or with additional compression.

4. Material showed results that are similar of other sapropel thermal insulation materials for conductivity, but worse for mechanical strength because the manufacture technologies differed.
5. Material shows better thermal conductivity than hemp-lime materials but has weaker mechanical strength.
6. Further tests should focus on improvement of mechanical strength which can be achieved using thermal treatment during the curing.
7. In the case of using the material as a thermal insulation - problems regarding fire protection and biological resistance should also be solved, as there are no mineral additives for the material at this moment.

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