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Ecological Materials for Frame Housing

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***Abstract* – The purpose of this study is to investigate and produce lightweight, ecological composite materials (hemp concrete) by using building lime, cement as binding agents and hemp (Cannabis sativa) shives as a renewable raw material from agriculture.**

As a result of the research, composites based on cement, lime and hemp shives have been elaborated that can be used as a material for frame walls. There have been investigated material properties such as compressive strength, density and thermal conductivity.

Keywords – ecological materials, hemp, hemp concrete, shives.

I. Introduction

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. But nowadays in the world most nations are dependent on energy sources which cannot be renewed or regenerated quickly enough to keep pace with their use. Therefore it is important to find new solutions and/or replace components with renewable or potentially renewable resources [1] -[3].

Plant fibres from wood and agricultural crops like flax and hemp are renewable materials, building up a potential for development of "green", biodegradable, sustainable, energy-efficient products and replacing harmful for the environment fossil hydrocarbon materials. Natural fibres have advantages compared to synthetic materials in being ecologically and toxicologically harmless, biological degradable and CO2–neutral [2], [4].

In recent years, the use of renewable agricultural crops as raw materials in the building industry enables to develop a sustainable environment and to solve environmental problems. These crops have a huge potential in the future because vegetable fibres are reasonably cheap and readily available; they require only a low degree of industrialization for their processing and a small amount of energy for their production, and therefore costs are low [5].

This article concerns industrial hemp (Cannabis sativa) that can reach a height of 1.5–3 m in Northern Europe. It is a fast growing, multi-purpose and annual herbaceous plant. The hemp fibres are situated in the bast of the hemp plant, and have a high tensile strength. Inside the stem of the hemp plant, there is its woody core, called shive (Fig. 1). The bast fibers are 10 to 100 times longer than the woody fibres in the shives. Their diameters are approximately the same; however the cell walls of the bast fibres are 5 to 10 times thicker than those of woody fibres. In hemp 60 – 80 % w/w of the stem is shives which consist mainly of cellulose (34 – 48 % w/w), hemicellulose (21 – 37 % w/w) and lignin (16 – 28 % w/w) (Tab.1) [5], [6].

Up to now hemp shives have been used in different industrial applications of hemp products such as animal bedding, mulch, compost and for combustion. However, today hemp shives can be used in high-quality products such as hemp concrete and fibre board [5].

Now in the EU, hemp concrete is a perspective building material that combines a lime-based binder and woody core of the hemp plant. This material has many advantages such as low density, good thermal insulation, breathability, carbon sequestration, fire resistance, protection from infestation, however it is not load-bearing and must be used in combination with a load-bearing frame [5], [7], [8].

There are several wall building methods from hemp concrete: tamping, spraying and blocks. It can be used as insulating wall infill, roof insulation, insulating wall plaster, ground/intermediate floor insulating slab and insulating floor screed. Conventional walls of brick or wood are built up of several layers, where each layer fulfils one or more of the above-mentioned functions. Apart from a load-bearing wooden framework and a lime rendering, hemp concrete does not require any other additional building materials to create a well-functioning wall[5], [8], [9], [10].

Hemp is suitable for use in a wide range of products such as paper, textiles, constructions, biodegradable plastics and so on, but at the moment in Latvia there is the lack of products in which hemp can be used and the lack of a commercial market for these products. The use of hemp in hemp concrete could create a more viable market for hemp in Latvia.

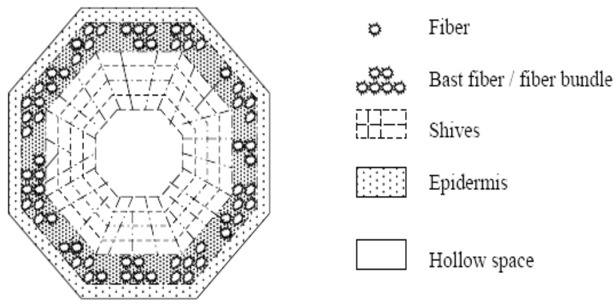


Fig. 1. Cross-section of a hemp stem [4]

TABLE 1 [4]

CHEMICAL COMPOSITION OF HEMP STEMS, FIBRES AND SHIVES

	Hemp stem	Hemp fibres	Hemp shives
Ash (% w/w)	-	4	1-2
Cellulose (% w/w)	70	55-72	34-44
Hemicellulose (% w/w)	22	7-19	31-37, 18
Lignin (% w/w)	6	2-5	19-28
Pectin (% w/w)	-	4-8	4
Water sol. mat. (% w/w)	-	2	-
Fat and wax (% w/w)	-	0.7-1.3	1

II. MATERIALS AND METHODS

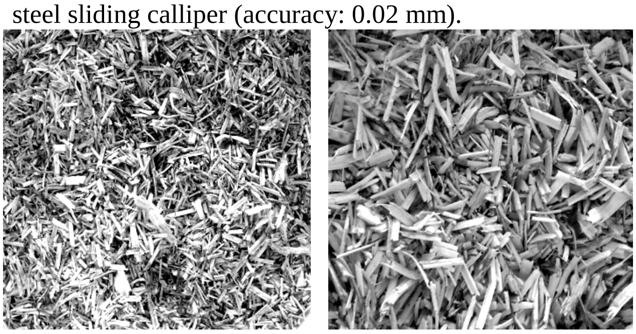
According to literature, due to the low density and high porosity of the hemp shives, the combination of hemp and a cementitious binder creates a building material with mechanical, thermal and acoustic properties that differ from those of conventional concrete. It has a lower density, a lower thermal conductivity, and better acoustic insulation properties.

The aim of this research is to determine an optimal composition of hemp concrete mix, using varying component pre-treatments and cementitious binder compositions in combination with hemp shives grown in Latvia (Fig. 2).

The hemp cultivar Bialobrezskie (designated B) and clone Pūriņi (designated P) were acquired from a local trial area of Agricultural Science Centre of Latgale. These hemps were sown on 13th May 2010 and were harvested accordingly on 7th and 16th September 2010 [11].

The binders used in these experiments were hydrated lime (calcium hydroxide) and building cement (CEM I 42.5 N).

The granulometric analysis of hemp shives in three dimensions (length, width, thickness) was carried out, using a steel sliding calliper (accuracy: 0.02 mm).



Pūriņi *Bialobrezskie*

Fig. 2. Hemp shives

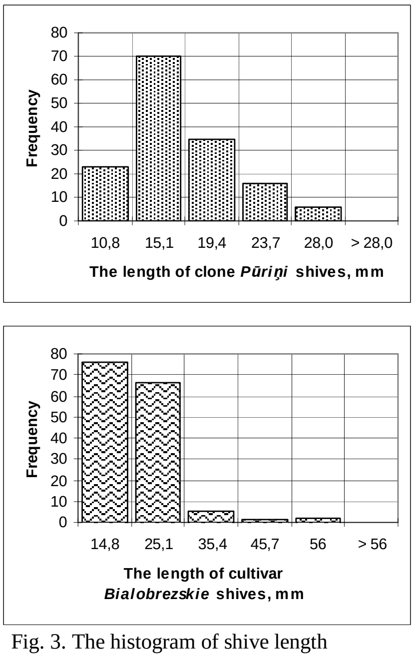


Fig. 3. The histogram of shive length

The distribution of clone Pūriņi shive length was more symmetrical than that of the cultivar Bialobrezskie. It was indicated by practically equal values of modal, medial and arithmetical mean length (respectively 14.69, 14, 14 mm) (Fig. 3). It seems that the distribution of P shives is better because their length and length variance are less, and short shive fraction allows filling spaces of mixture better. This parameter can and should be regulated technologically in hemp pre-treatment processing. In order to implement a proper distribution of shive length in practice, experimentally produced specifications are needed based on the length distribution of shives corresponding to finished product characteristics.

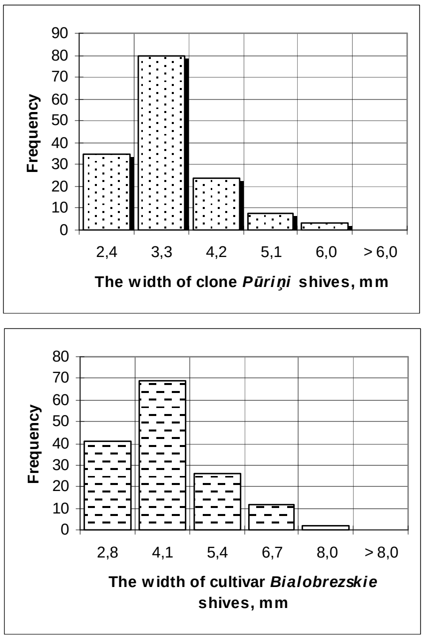


Fig. 4. The histogram of shive width

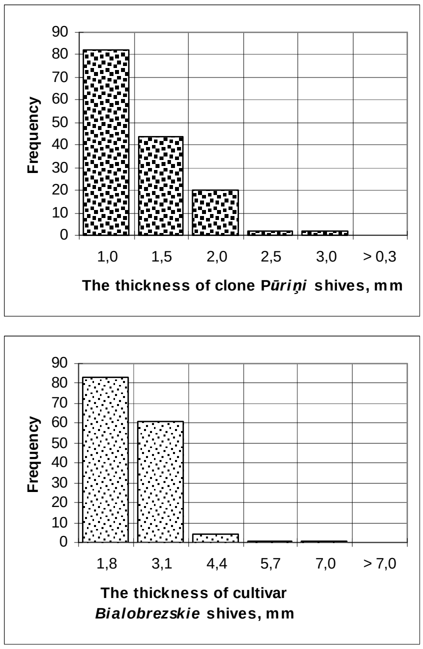


Fig. 5. The histogram of shive thickness

The distribution of P and B shive width can be regarded as equivalent, while B is a little bit shifted to the side of the highest thickness values of shives (Fig. 4). This parameter is more difficult to regulate in technological processes, because stem circumference and diameter of the central channel affect shive width, which has many controllable and uncontrollable factors and their interaction effect.

Fig.5 shows that the thickness of B shives (1.8-3.1 mm) greatly exceeds the values of P shives (1-2 mm). This parameter is dependent on the cultivar of hemp, agricultural engineering, soil and climatic conditions, therefore the manufacturing management options of a particular cultivar (variety) are limited.

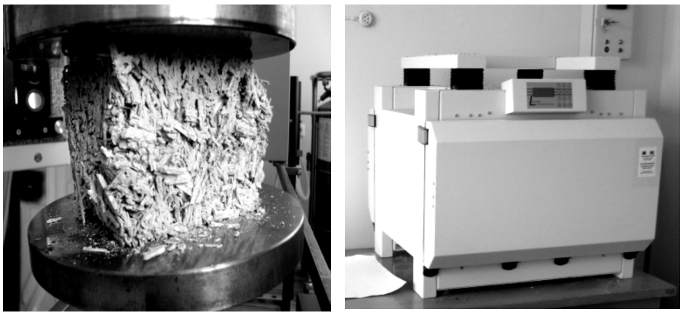
Four mixes of different binders used in the specimens (S1=250 g/dm3; S2=400 g/dm3; S3=600 g/dm3; S4=400 g/dm3 + 300 g/dm3 of dolomite siftings) were prepared. The largest amount of shives (43-44% w/w) was used in mix S1, but the lowest amount (17-18% w/w) was used in mix S4.

Two different sized specimens were made (Fig. 6). Steel moulds measuring 100 x 100 x 100 mm were used for preparation of the cube specimens. For the larger specimens (plate) 350 x 350 x 100 mm wood moulds were used. The steel moulds were lined with oil, but wood moulds were lined with plastic household film for the ease of extraction of the specimen from the mould after preparation.

The lime and cement were mixed with water in a separate container. Then the binder mix was weighed and added to the hemp and mixed together by hand in homogeneous mass. The mix was tamped into the moulds.

Cube Plate

Fig. 6. Forms of specimens



Zwick Z100 FOX600

Fig. 7. Testing machines

The specimens were cured for 2 days in an indoor climate at approximately +20°C and then removed from the moulds. After that specimens were wrapped in a household film, so that they would not dehydrate, and stayed 7 days in an indoor climate. Then curing was continued without a household film for another 8 to 10 weeks at an average temperature of +19°C (±2°C). After 8 – 10 weeks of curing, the specimens were tested with electromechanical testers Zwick Z100 and FOX600 (Fig. 7). Curing conditions were equivalent for all specimens.

The density of specimens is calculated using Eq. (1):

$$\rho = \frac{m}{V}, (1)$$

where ρ is the density, m is the mass, and V is the volume of sample.

Compression tests were carried out to determine the compressive strength and modulus, compressive behavior curves were fixed. Compressive strength is calculated using Eq. (2):

$$\sigma = \frac{F}{A}, (2)$$

where F is force in N and A is the cross-sectional area of the specimen in mm^2.

Statistical analyses have been carried out using the Microsoft Excel.

III. Results

A. Density

The density test results of cube specimens, after curing summarized in Table 2, show a wide range of density values from 266 to 749 kg/m3 with the average composite density ρ=525 kg/m3.

The density of cube specimens decreased linearly with the increased amount of hemp shives in a mix. The lowest values were observed for the mixtures of 43 – 44% w/w in composition (S1), the highest values were shown by mixtures of 18% w/w shives in composition (S4).

The results of density measurements of plate type samples are summarized in Table 3. The highest density (708 kg/m3) was shown by a specimen with 12% w/w shives, but no significant differences were found between mixtures P S2 and B S2 with 18% w/w/ shives.

TABLE 2

RESULTS OF CUBE SPECIMENS DENSITY

Mark	Mix	Average density, kg/m^3
P250	S1	331
P400	S2	455
P600	S3	629
P400+300	S4	751
B250	S1	296
B400	S2	427
B600	S3	547
B400+300	S4	657

TABLE 3

RESULTS OF PLATE DENSITY

Mark	Mix	Average density, kg/m^3
P plate	S2	508
P plate (dolomite)	S4	708
B plate	S2	482

B.Moisture

The average moisture content of the hemp cube specimens after moulding was 48% w/w. Before testing this value was 4 – 7% w/w. The curing occurred rapidly during four weeks.

C.Compressive Strength compar

The compressive strength of hemp concrete varies depending on the exact mix and age of the material. The results of compressive strength tests for the mixtures of cube specimens ranged from 0.15 MPa to 1.39 MPa, depending on the composition of the mixture. Table 4 shows an average compressive strength of cube specimens. Specimen B250 S1 showed the lowest compressive strength, while specimen

P300+400 S4 showed the highest value. Basically data from other studies show similar values. The highest results were obtained for mixtures with 25% w/w shives (S3), while mixtures with 43 – 44% w/w shives (S1) showed the lowest values. The values of compressive strength are relatively low in comparison with such load-bearing materials as aerated

(2-4 MPa) and expanded clay blocks (3-5 MPa). Therefore, hemp concrete must be used in combination with the load-bearing steel, wood or concrete frame.

TABLE 4

RESULTS OF CUBE SPECIMEN COMPRESSIVE STRENGTH

Mark	Mix	Average compressive strength, MPa
P250	S1	0.16
P400	S2	0.55
P600	S3	1.17
P400+300	S4	1.16
B250	S1	0.18
B400	S2	0.74
B600	S3	0.89
B400+300	S4	0.69

D.Thermal Insulation

Thermal conductivity has been tested for three different mixtures, and its values ranging from 0.160 to 0.224 W/mK are shown in Table 5.

The data from Table 4 show that there are no significant differences between thermal conductivity of Purini and Bialobrezskie plate samples as value λ of P S2 being 0,127 W/mK only slightly differs from B S2 λ = 0,121 W/mK. Thermal conductivity of the obtained specimens is better than that of such building materials as wood-fibre plates (0,15W/mK) or wood particle boards (0,14 W/mK) of the same density (Table 6).

TABLE 5

RESULTS OF THERMAL CONDUCTIVITY

Mark	Testing time, days	Density, kg/m^3	U, W/(m^{2}K)	$\lambda_{average}$, W/mK
P S2	after 21 days	546	1.69	0,164
	after 35 days	508	1.31	0,127
B S2	after 24 days	533	1.77	0,175
	after 45 days	482	1.24	0,121
P S4	after 22 days	760	2.38	0,224
	after 46 days	708	1.70	0,160

TABLE 6

COMPARISON OF TYPES OF INSULATION [12]

Insulation	Density, kg/m^3	λ , W/mK
Ecowool	70	0.04
Flax	30	0.04
Hemp	30	0.045
Glass wool	20	0,035
Wood-fiber plates	600	0.15
Wood particle boards	500	0.14
Magnesium oxide boards	950-1050	0.21
Natural cork flooring	90-160	0.1
P // B plate	500	0.12
P plate (dolomite)	720	0.16

IV.CONCLUSIONS

Non-renewable resources are consumed much faster than nature can create them; therefore, there is a necessity for renewable and recyclable materials, which can be utilized after their life cycle. Hemp as one of annual renewable sources is suitable for the use in a wide range of products such as paper, textiles, biodegradable plastics, etc.

Hemp concrete, which consists of a lime-based binder, shives and water, is a perspective building material in the EU. This is a multi-functional, sustainable, lightweight, self-bearing material with a good thermal insulation capacity. The use of hemp in hemp concrete could create a more viable market for hemp products in Latvia.

Proposed compositions of hemp concrete from two cultivars hemp grown in Latvia and lime-based binders show mechanical properties similar to those of contemporary hemp concrete and can be used in combination with load-bearing frames to build wall structures without the usage of additional thermal insulation materials. However, future research could focus on the use of additives, which could increase the mechanical durability of the hemp concrete.

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Anete Stikute, Silvija Kukle, Genādijs Šahmenko. Ekoloģiski materiāli karkasa būvēm
Mājoklis ir viena no cilvēka pamatvajadzībām, kas sevī ietver milzums materiālu un enerģijas resursu, taču mūsdienās vajadzība pēc resursiem ir daudz lielāka, nekā tie spēj atjaunoties, tāpēc iespējami efektīvāk jāizmanto esošie krājumi un/vai jāmeklē jauni risinājumi no atjaunojamiem resursiem. Šobrīd par vienu no nozīmīgākajiem risinājumiem vides problēmu risināšanā tiek uzskatīts atjaunojamo lauksaimniecības kultūru (linu, kaņepju, salmu utt.) kā izejvielu izmantošana būvniecības nozarē, veicinot ekoloģiskas un ilgtspējīgas būvniecības attīstību. Latvijas apstākļiem piemērots risinājums varētu būt atjaunojamo, ātri augošo kaņepāju lietošana biodegradējamu un ilgtspējīgu materiālu izstrādē, piem., kompozītmateriālos no kaņepju spaļiem un saistvielām. Kaņepju spaļu izmantošana kaņepju betonā varētu palielināt komerciālo noieta tirgu kaņepju bāzes izejvielām Latvijā, tāpēc darba mērķis bija noteikt optimālo saistvielu maisījumu attiecību mehāniski izturīgam materiālam. Rezultātā iegūts viegls būvmateriāls, ko var izmantot ēkās kā konstruktīvu siltumizolējošu sienu materiālu vai kā siltumizolācijas materiālu. Rūpniecisku prototipu veidošanai gan vēl nepieciešams veikt virkni pētījumu stabilas un prognozējamas struktūras veidošanai, kā arī informatīvus pasākumus, lai pierādītu, ka šāda veida materiāli ir piemēroti mūsu klimatiskajiem apstākļiem.

Анете Стикуте, Силвия Кукле, Генадий Шахменко. Экологические материалы для каркасных зданий
Жилище является одним из основных потребностей человека, оно включает в себя целый ряд материальных и энергетических ресурсов. К сожалению, сегодня потребность в ресурсах намного больше, чем они могут регенерироваться, поэтому необходимо наиболее эффективно использовать существующие запасы или искать новые решения на основе возобновляемых ресурсов. В настоящее время одним из решений экологических проблем считается использование возобновляемых сельскохозяйственных культур (лен, конопля, солома и т.д.) в качестве сырья для производства строительных материалов. Таким образом можно содействовать развитию экологического строительства. В латвийских условиях подходящим решением могло бы быть использование возобновляемой, быстро растущей конопли в создании биодеградируемых и устойчивых экологичных материалов. Налаживание производства композитов на основе костры конопли и вяжущих могло бы расширить рынок сбыта сырья индустриальной конопли в Латвии. Целью работы является определение оптимального соотношения компонентов смеси для создания механически прочного материала. В результате получен легкий строительный материал, который можно использовать в зданиях в качестве теплоизоляционного, а так же конструктивно теплоизоляционного материала для стен. Для разработки промышленного прототипа необходимо провести ряд исследований по созданию стабильной и предсказуемой структуры, а также провести информационно-просветительскую деятельность, чтобы доказать, что такого рода материалы подходят для нашего климата.