International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 6 Issue 6|| June 2017 || PP. 20-27

Investigation of Energy Efficient Thermal Insulating Composites from Hemp Shives and Starch

Arūnas Kremensas, Saulius Vaitkus, Sigitas Vėjelis, Agnė Kairytė, Giedrius Balčiūnas
Scientific Institute of Thermal Insulation, Vilnius Gediminas Technical University, Linkmenų st. 28, LT-08217 Vilnius, Lithuania

Abstract : *This work presents the investigation results of physical-mechanical properties of fibrous hemp composite specimens produced from hemp shives and starch used as a binding material. For this purpose specimens with different amount of binding material, density and granulometric composition were used. Experimental results show that strength properties of composites linearly depend on the density of the material, as well as the density of hemp composites in all cases has the influence on change in thermal conductivity. During the research of mechanical properties it was determined that specimens with greater density and quantity of binding material had the greatest strength..*

Keywords : *hemp shives, starch, composite, thermal insulating – structural materials, compression, thermal conductivity.*

I. INTRODUCTION

In recent years due to increasing prices of energy resources, production of classic building materials becomes increasingly difficult due to their expensiveness because prime cost of energy, which is necessary to produce a product, is ~ 40 %. One of the most dynamic industries in the world – materials produced from recycled wastes or renewable resources without harmful additives for health and environment. The greatest energy consumption for heating of buildings depends on energy efficiency of building envelopes. Energy consumption, which is necessary for heating of buildings, comprises of ~ 50 % of all energy use [1]. In order to build environmental friendly and energy efficient contemporary buildings it is appropriate to use renewable resources [2, 3]. Currently, renewable resources such as hemp, flax, jute, straw, different types of wood are increasingly used for production of thermal insulating – structural materials [4-11].

These materials may be used as loose-fill materials to fill the carcass or with various binders (lime, clay, starch, gypsum and etc.) or their compositions. Such materials must have low thermal conductivity and sufficient strength properties to be suitable for usage in building envelopes and compete with contemporary efficient thermal insulating – structural materials [2, 4-11]. Fibrous hemp is a Canabissativa plant species which has low quantity of tetrahydrocannabinol [12]. Fibrous hemp is a plant which easily adapts to new growth conditions and is characterizedby high speciesdiversity[13]. It is one of the rational plants because all its parts may be used in industry.

Two types of raw materials which may be used in construction are produced from fibrous hemp: hemp shives which are produced by chopping woody core of the stem and hemp fibres which are obtained by separating fibres from stem[14]. Performed investigations showed that fibrous hemp shives are suitable for production of thermal insulating – structural composite materials because of its cellular structure. Fibrous hemp shives are loose material which has two types of porosity: internal shives porosity and porosity which forms between the shives[15]. It was determined that internal porosity of hemp shives reaches 57 % [16] and size of pores between the shives depends on shives granulometric composition and it is approximately 1 mm. Respectively, internal porosity of hemp shives consists of 15 % pores with a size of 70 μm and 85 % pores with a size of 400 μm[15]. Due to porous structure of hemp shives and high internal capillarity it is difficult to choose water content (hemps may absorb high content of water – up to five times by mass). Another issue is formation, since hemp shives are light enough (density ranges from 50 kg/m^3 to 100 kg/m^3), they cannot be pressed because such process causes destruction of porous structure. Therefore, the most effective formation process is projection. Conducted literature analysis showed that physical-mechanical properties of hemp composites are sufficient and this material may be used as thermal insulating-structural material for building envelopes. The aim of this work was to investigate physical-mechanical properties of organic thermal insulating-structural composite specimens produced from fibrous hemp and starch as a binding material. The specimens samples of thermal insulating – structural composites were produced and their short-term compression and thermal conductivity dependences on density and etc. were examined.

II. MATERIALS AND METHODS

Hemp shives grown in a Lithuania used as raw materials for use of in a composite. For production of composites, hemp stems as a general filler were used two different hemp compositions (Fig. 1). Hemp shives were prepared from dry hemp stems by manually separating long fibres. After eliminating long fibres hemp stems were milled by rotary mill. Then, from obtained hemp shives short fibres were separated and the rest hemp shives of various sizes were sieved through laboratory sieves. For this work the fractions of hemp stem shives used in this work varied from 2.5÷5.0÷10.0 mm and chopped hemp shives (mix varied from: 0.10 – 0.16 mm (partial residue 0.13%); 0.16 – 0.315 mm (3.19%); 0.315 – 1.25 mm (44.55%); 1.25 – 3.15 mm (51.29%); 3.15 -5.6 mm (0.84%)) .

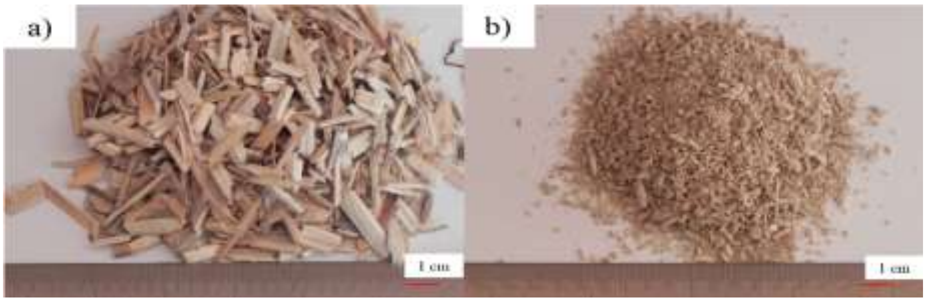

Fig. 1. Hemp shives slices: a) long and short hemp shives; b) chopped hemp shives

The mechanical and thermal insulation properties of hemp composites depended on micro and macrostructure. The cellular structures of representative hemp shives are shown in Figure 2 and Figure 3.

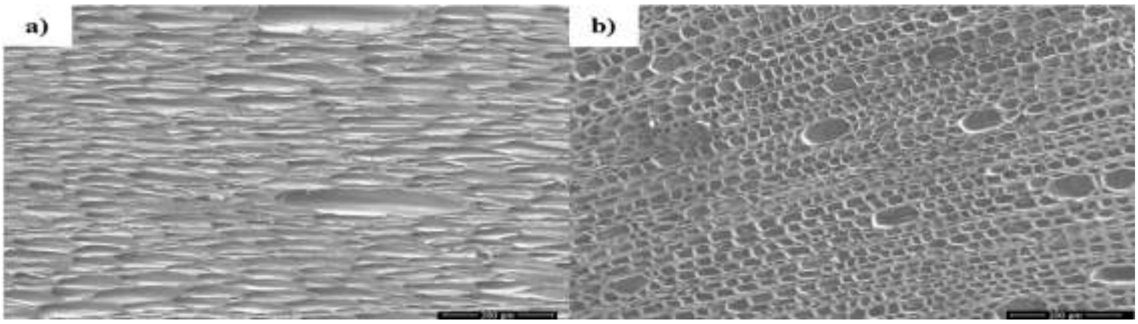

Fig. 2. The cellular structures of hemp shives (magnification x200): a) parallel; b) perpendicularly

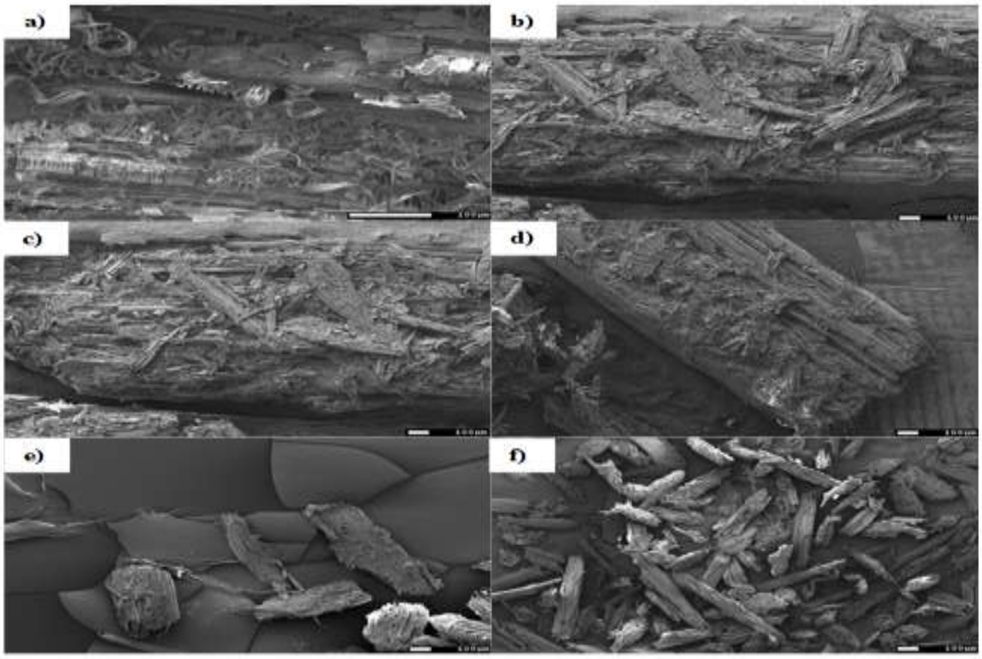

Fig. 3. The hemp shives: a) shives slices typical (fractions 2.5÷5.0÷10.0 mm, magnification x200); b) chopped hemp shives (fraction 3.15 – 5.6 mm, x50); c) chopped hemp shives (1.25 – 3.15 mm, x50); d) chopped hemp shives (0.315 – 1.25 mm, x50); e) chopped hemp shives (0.16 – 0.315 mm, x50); f) chopped hemp shives (0.10 – 0.16 mm, x50)

The bulk density of hemp shives were ~100 kg/m^3 and chopped hemp shives ~128 kg/m^3, the amount of hemp materials were constant – 500 g. Density was determined by weighting (200±1) g of hemp materials which were put in cylinder (internal diameter was of 205 mm, height – 110 mm) which was placed on a metal plate. The metal thickness gauge, which disc mass formed the load 250±5 Pa, was inserted into cylinder. The needle was drawn down vertically to pierce the hemp materials specimen till the needle reached the surface of metal plate. The corps with disc of thickness gauge was drawn down on the specimen. The height of hemp materials specimens was determined after 5 min. Before the formation of hemp composite specimens, hemp materials were conditioned at 23±2 °C ambient temperature and 50±5 % relative air humidity.

Corn starch $(C_6H_{10}O_5)_n$ was used as a binding material. Physical properties of starch: specific gravity ~1.5 g/cm^3; specific surface ~2840 cm^2/g; moisture ~12.3 %; quantity of ashes <0.10 %; pH ~5.3; quantity of proteins (Nx6.25) < 0.40 %. Part of the specimens was produced using kaolin as an additive for binding material, which increases the strength of the composite. The amount of kaolin was 10 %; 25 %; 50 % of the starch amount. Physical properties of kaolin: moisture ~ 1.0 %; bulk density ~ 600 kg/m^3; density 2650 kg/m^3; pH ~ 8.0. Hemp composite specimens were formed by multiplexing them in the metal forms. Semi-finished specimens were dried for a day in the power rack (150±5) °C until they reached the constant mass. In accordance with experimental results density variation interval ~ 183÷543 kg/m^3 of hemp composite specimens was determined. Compression tests were carried out using hemp composite specimens in a form of which the size of (shives with starch, hemp shives with starch and kaolin 100x100x100 mm and chopped hemp shives with starch 50x50x10 mm) have been prepared. Conventional compressive strength σ_m or $\sigma_{10\%}$, initial modulus of elasticity E were calculated for every tested hemp composite specimen. For compression tests computerized testing machine H50KS (Hounsfield, England) was used, loading speed was $0.1 \cdot d$ mm/min. (where d - thickness of the specimen) [17], error of load gauge varied from 1 to 11 N. Compression tests and conditioning were conducted at 23±2 °C ambient temperature and 50±5 % relative air humidity.

Thermal conductivity of hemp composites was determined in accordance with [18] by measuring heat flux and temperature difference between specimen surfaces. All hemp composite specimens were conducted at 23±2 °C ambient temperature and 50±5 % relative air humidity for at least 24 hours. Temperature difference between measuring plates was 10 °C. Thermal conductivity was determined at the mean temperature of 10°C. Computerized thermal conductivity apparatus FOX-304 LaserComp is employed. Specimens for thermal conductivity tests had size of 300x300x(from 10 to 75) mm. Mathematical-statistical methods [19] were used for evaluation of experimental data of hemp composites physical properties.

This work presents linear regression dependences which are characterized by the simplicity of calculations and possibility to determine quantitative values of hemp composites physical properties:

$$\overline{Y}_x = b_0 + b_1 \cdot X \quad , \qquad (1.0)$$

where: $\overline{Y}_x$ - resultative indicator of the mean value; X - factorial indicator; b_0; b_1 - constant coefficients obtained by experimental data using least square method [20-23].

In the case of linear dependence relationship degree of two variables in regression scheme is defined by correlation coefficient $R_{x \cdot y}$. For the treatment of its values so called determination coefficient was used, it shows what variation part of tested indicator forms variations of controlled factors. When the relation is linear, determination coefficient is equal to the square of the correlation coefficient $R^2_{y \cdot x}$.

Indicator of observed scatter of the results around empirical regression line is standard deviation S_r :

$$S_r = \sqrt{\frac{\sum \left(Y_i - \overline{Y}_i\right)^2}{n - m}} \quad , \qquad (1.1)$$

where: Y_i; $\overline{Y}_i$ - experimental and computational i-th indicator value (Eq (1.0)); n - number of tests; m - number of constant assessed parameters in empirical equation ($m = 2$, when the equation is linear).

III. RESULTS AND DISCUSSION

The efficient use of most thermal insulating-structural materials mostly depends on such properties as strength, deformability and thermal conductivity [24, 25]. The values of these parameters are very important indicators when dealing with their usage for one or another use in construction. The compressive strength of hemp composite is an important indicator because this material may be used as thermal insulating-structural material which should withstand enlarged compressive loadings. Compressive strength and deformability of hemp composite depend on uniformity of structure of the materials and various technological parameters (quality of fillers, pressure, hardening temperature and etc.). Fig. 4 shows ultimate compressive stress σ_m and $\sigma_{10\%}$ of hemp composite dependence on specimens' density. The comparison of the experimental results showed that the composition of the first and second group of samples can be combined into a single array. At the same time, the chopped hemp shives and starch composition comprises a separate array of experimental results. On the basis of experimental results, relation between ultimate compressive stress σ_m and $\sigma_{10\%}$, MPa, and specimens' density ρ, kg/m^3, which may be approximated by the regression equation, is of the form (see Table 1).

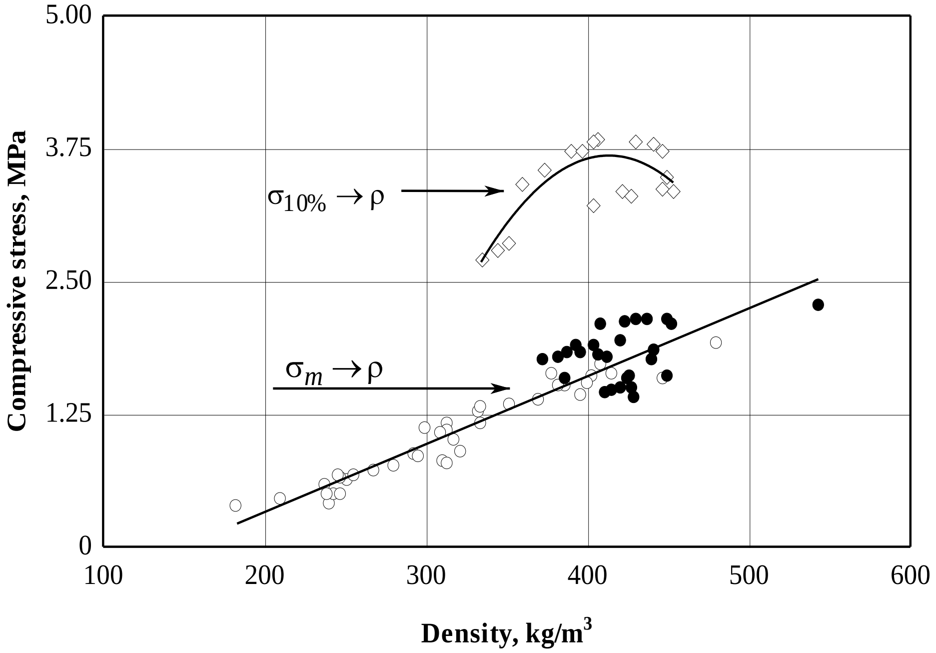

Fig. 4. The dependence of ultimate compressive stress $\overline{\sigma}_m$ and $\overline{\sigma}_{10\%}$ of hemp shives composite specimens on their density. ○ – experimental data of hemp shives with starch; ● – experimental data of hemp shives with starch and kaolin; ◊ – experimental data of chopped hemp shives —— empirical line of regression dependence of specimens' ultimate compressive stress $\overline{\sigma}_m$ on their density

Table. 1. Statistical data results for compressive stress of hemp composite

Regressive equation No.	The number of test series n	Values of constant coefficients of equation			S_r, MPa	$R^2_{\sigma \cdot \rho}$
		b_0	b_1	b_2		
1.2	$\overline{\sigma}_m = b_0 + b_1 \cdot \rho$ (1.2)*					
	65	-0.951	0.00639	-	0.122	0.866
1.3	$\overline{\sigma}_{10\%} = b_0 + b_1 \cdot \rho + b_2 \cdot \rho^2$ (1.3)**					
	18	-23.64	0.132	-0.00016	0.227	0.643

**(hemp shives with starch + hemp shives with starch and kaolin), **(chopped hemp shives)*

The results of the statistical analysis of the data are given in Table 1. The columns labeled (1.2)–(1.3) define the empirical relations. It should be noted that the $R^2_{\sigma \cdot \rho}$ values range from 0.643 to 0.866. Therefore, the empirical relations (determined by the regression analysis) may be used in predicting the stress values σ_m and $\sigma_{10\%}$, of hemp shives with starch + hemp shives with starch and kaolinspecimens under short-term compression loads.Ultimate compressive strength of specimens when the density is ranging from 183 kg/m^3 to 543 kg/m^3 may be determined in accordance with empirical equations (1.2-1.3). Analysis of experimental data of short-term compression showed that destruction of specimens with low density is brittle. Plastic destruction of the specimen occurs when the density increases. It may be stated that the value of ultimate strength linearly proportionally increases with the increase of density of the material. Investigations of other authors showed similar results of hemp shives with different compositions of binding materials (lime mixture and cement) [7-10]. The investigation of composite from fibrous hemps and lime as binding material was presented in the article [7-10]. Hemp composite specimens with a density ranging from ~ 417 kg/m^3 to ~ 551 kg/m^3 were made, and their compressive strength varied from ~ 0.18 MPa to 0.80 MPa. Investigations of strength properties made by other authors showed similar values of hemp composites with binder from lime [7]. Hemp composites with various compositions of binder (lime and cement mixture) were investigated when the density was ranging from ~587 kg/m^3 to ~733 kg/m^3 and the compressive strength varying from ~ 0.15 MPa to 0.83 MPa [2]. Comparison of our and other authors' results showed that hemp composites with a starch binder have higher compressive strength. The initial modulus of elasticity of hemp composite is one of the most important deformability properties which characterize the suitability for usage as a thermal insulating-structural material in building envelopes where enlarged loadings occur. Fig. 5 shows initial modulus of elasticity E of hemp composite dependence on specimens' density. On the basis of experimental results, relation between initial modulus of elasticity $\overline{E}$, kPa, and specimens' density ρ , kg/m^3, was determined and its empirical regression equation may be expressed as follows (see Table 2).

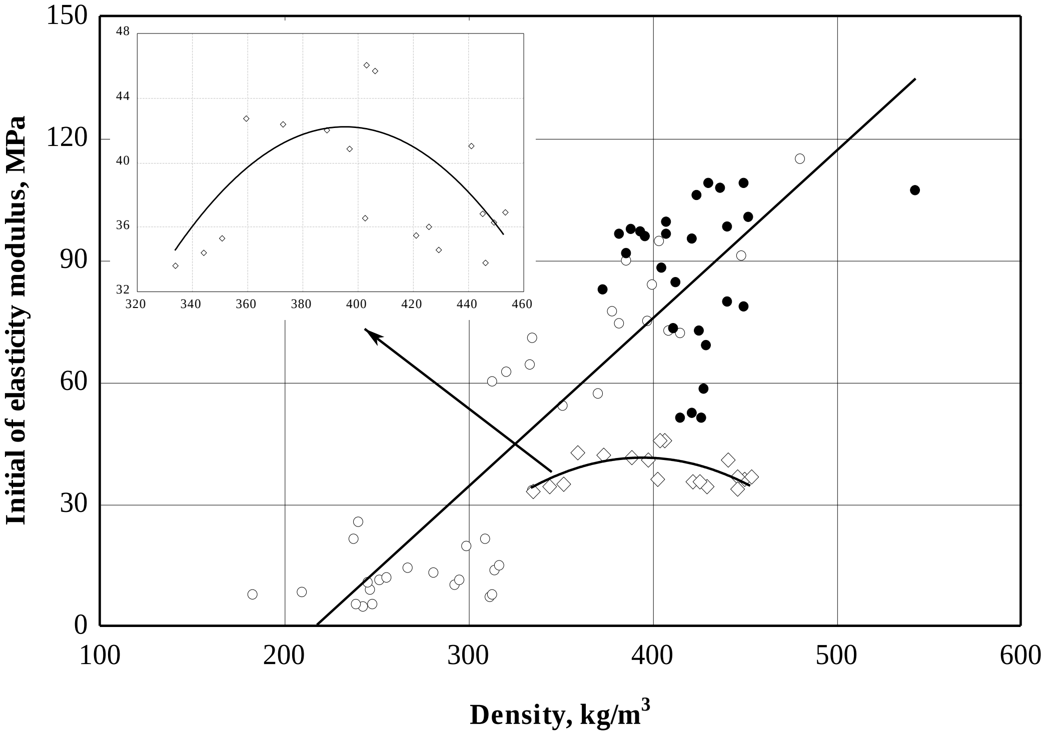

Fig. 5. The dependence of initial modulus of elasticity $\overline{E}$ of hemp shives composite specimens on their density. ○ – experimental data of hemp shives with starch; ● – experimental data of hemp shives with starch and kaolin; ◊ – experimental data of chopped hemp shives; —— empirical line of regression dependence of specimens' initial modulus of elasticity $\overline{E}$ on their density

The results of the statistical analysis of the data are given in Table 2. The columns labeled (1.4)–(1.5) define the empirical relations. It should be noted that the $R^2_{E\cdot\rho}$ values range from 0.394 to 0.759. Ultimate initial modulus of elasticity E of hemp shives with starch + hemp shives with starch and kaolin specimens when the density is ranging from 220 kg/m^3 to 543 kg/m^3 may be determined in accordance with empirical equations (1.4).

Table. 2. Statistical data results for initial of elasticity modulus of hemp composite

Regressive equation No.	The number of test series n	Values of constant coefficients of equation			S_r, MPa	$R^2_{E\cdot\rho}$
		b_0	b_1	b_2		
1.	$\overline{E} = b_0 + b_1 \cdot \rho$ (1.4)*					
	65	-89.88	0.413	-	18.1	0.759
2.	$\overline{E} = b_0 + b_1 \cdot \rho + b_2 \cdot \rho^2$ (1.5)**					
	18	-274.1	1.598	-0.00202	3.37	0.394

*(hemp shives with starch + hemp shives with starch and kaolin), **(chopped hemp shives)*

Fig. 6 shows the hemp composite experimental data relation between initial modulus of elasticity E and ultimate compressive stress σ_m which is expressed by regression equation (see Table 3).

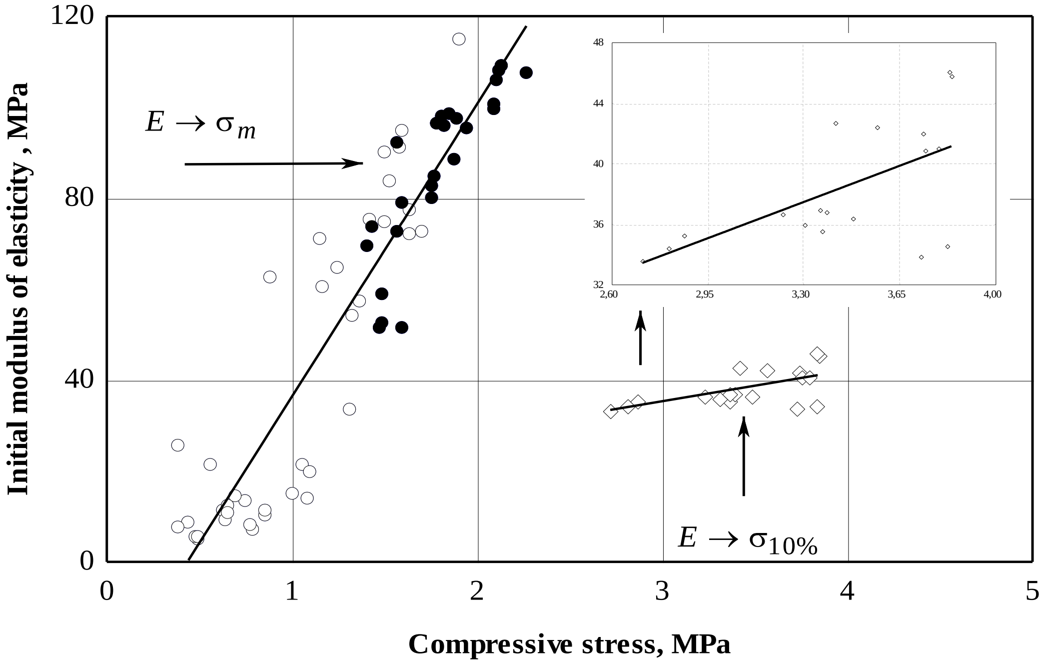

Fig. 6. The dependence of initial modulus of elasticity $\overline{E}$ of hemp shives composite specimens on ultimate compressive stress σ_m or $\sigma_{10\%}$. ○ – experimental data of hemp shives with starch; ● – experimental data of hemp shives with starch and kaolin; ◊ – experimental data of chopped hemp shives; ── empirical line of regression dependence of specimens' initial modulus of elasticity $\overline{E}$ on ultimate compressive stress σ_m or $\sigma_{10\%}$

Table. 3. Statistical data results for compressive stress of hemp composite

Regressive equation No.	The number of test series n	Values of constant coefficients of equation		S_r, MPa	$R^2_{E\cdot\sigma}$
		b_0	b_1		
1.	$\overline{E} = b_0 + b_1 \cdot \sigma_m$ (1.6)*				
	65	-28.01	64.34	13.37	0.869
2.	$\overline{E} = b_0 + b_1 \cdot \sigma_{10\%}$ (1.7)**				
	18	14.80	6.84	3.35	0.365

(hemp shives with starch + hemp shives with starch and kaolin),(chopped hemp shives)*

The results of the statistical analysis of the data are given in Table 3. The columns labeled (1.6)–(1.7) define the empirical relations. It should be noted that the $R^2_{E\cdot\rho}$ values range from 0.365 to 0.869.

Ultimate initial modulus of elasticity E of hemp shives with starch + hemp shives with starch and kaolinspecimens when the compressive stress σ_m may be determined in accordance with empirical equations (1.6).

The work [7] presents the hemp shives composite with a binder initial modulus of elasticity value, which is formulated by power-law empirical equation. Obtained values are 2-3 times lower than the value of initial modulus of elasticity E calculated by us. Initial modulus of elasticity E of hemp composite was determined by us in accordance with the whole quasi-elastic area of stress-strain curve. Thus, it can be stated that deformability characteristics are more realistically described by our investigations. Results of initial modulus of elasticity of hemp composite with a binder obtained by other authors [9] showed similar values in comparison with our results. Experimental analysis of the results showed that change in physical-mechanical properties of hemp composite is very complicated process which depends on many parameters such as structure, thickness of the specimens and other characteristics. Density of a material is a key indicator which describes thermal conductivity of certain materials. Thermal conductivity of hemp composite specimens varies depending on specimens' density. When hemp composite density increases thermal conductivity linearly increases as well due to heat transfer by solid skeleton (Fig. 7). Properly chosen composition may lead to a production of efficient thermal insulating-structural material for building envelopes.

Fig. 7 shows initial thermal conductivity $\overline{\lambda}_{10^\circ C}$, W/(m·K), of hemp composite dependence on specimens' density ρ, kg/m^3. On the basis of experimental results, relation between thermal conductivity and specimens' density which may be approximated by regression equation (see Table 4).

Table. 5. Statistical data results for thermal conductivity of hemp composite

Regressive equation No.	The number of test series *n*	Values of constant coefficients of equation			S_r, MPa	$R^2_{\lambda_{10\,^\circ C}\cdot\rho}$
		b_0	b_1	b_2		
1.	$\overline{\lambda}_{10\,^\circ C} = b_0 + b_1 \cdot \rho$ (1.8)*					
	21	0.0257	0.00019	-	0.00331	0.970
2.	$\overline{\lambda}_{10\,^\circ C} = b_0 + b_1 \cdot \rho + b_2 \cdot \rho^2$ (1.9)**					
	18	37.80	-0.194	0.00025	1.20	0.994

(hemp shives with starch + hemp shives with starch and kaolin),(chopped hemp shives)*

The columns labeled (1.8)–(1.9) define the empirical relations. It should be noted that the $R^2_{E\cdot\rho}$ values range from 0.970 to 0.994. Therefore, the empirical relations (determined by the regression analysis) may be used in predicting the thermal conductivity (hemp shives with starch + hemp shives with starch and kaolin and chopped hemp shives).The determination coefficient $R^2_{\lambda\cdot\rho} = 0.970$ and $R^2_{\lambda\cdot\rho} = 0.994$ which shows that variation of mean value of thermal conductivity is 97.0 % and 99.4 % dependent on hemp composite specimens' density and only 3 % and 0.6 on other factors (uniformity of structure, technological parameters and etc.).

Other scientists [7] have studied fibrous hemp composites with a lime as and the hemp specimens with a density ranging from 417 kg/m^3 to 551 kg/m^3, thermal conductivity ranging from 0.179 W/(m·K) to 0.485 W/(m·K). The analysis shows that increase in thermal conductivity of hemp composite specimens is directly proportional to its density increase. When the density of hemp composite varies from 260 kg/m^3 to 444 kg/m^3 the value of thermal conductivity changes respectively from 0.074 W/(m·K) to 0.112 W/(m·K). During the experimental investigation of hemp shives with MgO-cement as a binding material following results were obtained: when the density varied from 1040 kg/m^3 to 1150 kg/m^3 the value of thermal conductivity changed respectively from 0.110 W/(m·K) to 0.115 W/(m·K) [26].

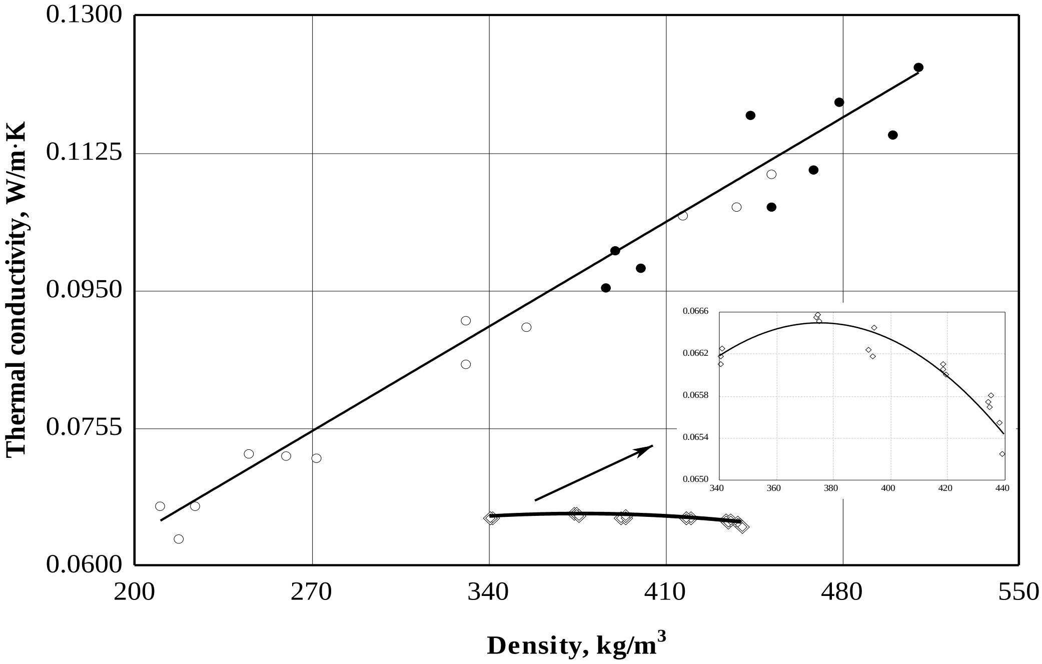

Fig. 7. The dependence of thermal conductivity $\overline{\lambda}_{10\,^\circ C}$ of hemp shives composite specimens on their density. ○ – experimental data of hemp shives with starch; ● – experimental data of hemp shives with starch and kaolin; ◊ – experimental data of chopped hemp shives; ——— − empirical line of regression dependence of specimens'

It was also determined that thermal conductivity of materials from renewable resources depends not only on density but also on the structure of the material, i.e. composition of formation mixture and technological parameters as well as orientation of the shives [25]. These statements are proved by investigations of other authors [24, 26]. They have concluded that nature of mechanical destruction of hemp composite depends on various parameters – structure, hardening temperature, relative air humidity and etc. It can be assumed that density of hemp composite is one of the most important indicators which indirectly define the relation of solid and gaseous phases in the material.

IV. CONCLUSIONS

On the basis of the experimental results it was determined that compressive strength of hemp composite is defined by ultimate stress σ_m or $\sigma_{10\%}$. Ultimate stress σ_m of hemp composite is dependent on materials density and may be calculated in accordance with obtained regression equations when density varies from 183 kg/m^3 to 543 kg/m^3. The relation between initial modulus of elasticity E and density and compressive stress σ_m of the hemp composite specimens was also determined. The relation between hemp composite thermal conductivity and density, from 210 to 510 kg/m^3, was determined and the value of thermal conductivity varied from 0.063 W/(m·K) to 0.12 W/(m·K). To evaluate this relation the regression equation was obtained.

REFERENCES

[1] UNEP-SBCI Buildings and Climate Change. Status, Challenge and Opportunities UNEP Publication, Paris, France; 2007.

[2] Bruijna PB, Jeppssona KH, Sandinb K, Nilssona C. Mechanical properties of lime–hemp concrete containing shives and fibres. Biosyst Eng 2009; 103: 474–479.

[3] Peris Mora E. Life cycle, sustainability and the transcendent quality of building materials. Build Environ 2007;42: 1329–1334.

[4] González-García S, Luo L, Moreira M, Feijoo G, Huppes G. Life cycle assessment of hemp shives use in second generation ethanol production. Biomass Bioenerg 2012;36: 268–279.

[5] Korjenica A, Petránekb V, Zachb J, Hroudová J. Development and performance evaluation of natural thermal-insulation materials composed of renewable resources. Energ Buildings 2011;43: 2518–2523.

[6] Kymalainen HR, Sjoberg AM. Flax and hemp fibres as raw materials for thermal insulations. Build and Environ 2008;43: 1261–1269.

[7] Elfordy S, Lucas F, Tancret F, Scudeller Y, Goudet L. Mechanical and thermal properties of lime and hemp concrete (‘‘hempcrete’’) manufactured by a projection process. Constr Build Mater 2008;22: 2117– 2123.

[8] Evrard A. Be´tons de Chanvre, Synthe`se des proprie´te´s physiques [Hemp Concretes, a Synthesis of Physical Properties]. Report. Construire en Chanvre, Saint Vale´rien, 2003 (in French).

[9] Arnaud L, Cerezo V. Qualification physique des mate´riaux de construction a` base de chanvre. [Physical Qualification of Construction Materials Based on Hemp]. Report. E´ coleNationale des Travaux Publics de l'E´ tat, De´partement Genie Civil etBaˆtiment, Vaulx-en-Velin, 2001 (in French).

[10] Cerezo V. Proprie´te´sme´caniques, thermiquesetacoustiques d'un mate´riau a` base de particulesve´ge´ tales: approcheexpe´rimentale et mode´lisationthe´orique. [Mechanical, Thermal and Acoustical Properties of a Material Based on Vegetable Particles]. Report. E´ coleNationale des Travaux Publics de l'Etat, L'Institut National des Sciences Applique´es de Lyon, Saint Vale´rien, 2005 (in French).

[11] Eboziegbe PA, Mizi F. Development of Wood-Crete building materials from sawdust and waste paper. Constr Build Mater 2013;40: 361-366.

[12] Small E, Marcus D. Hemp: A new crop with new uses for North America. In J. Janick and A. Whipkey (eds), ASHS Press, Alexandria, VA, 2002: 284-326.

[13] Mankowski J, Kolodziej J. Increasing Heat of Combustion of Briquettes Made of Hemp Shives. In: *2008 International Conference on Flax and Other Bast Plants*, Saskatoon, Canada, July 2008.

[14] Collet F, Bart M, Serres L, Miriel J, Porous structure and water vapour sorption of hemp-based materials. Constr Build Mater 2008;22: 1271–1280.

[15] Glé P, Gourdon E, Arnaud L. Acoustical properties of materials made of vegetable particles with several scales of porosity. Appl Acoust2011;72(5): 249–259.

[16] Ceyte IBC. Définition des caractéristiquesmécaniques de la chènevotte. Travail de Fin d'Études; 2008.

[17] EN 826:1996E. Thermal Insulating Products for Building Applications. Determination of Compression Behaviour; 1996.

[18] EN 12667:2001E. 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; 2001.

[19] Sakalauskas V. Statistics with Statistica. Margi raštai, Vilnius 1998 (in Lithuania).

[20] Aivazyan SA. Statistical study of relationships. Application of methods of correlation and regression analyses to processing experimental results [Статистическоеисследованиезависимостей. Применение методов корреляционного и регрессионного анализов и обработка результатов эксперимента]. Moscow: Metallurgy; 1968 (in Russian).

[21] Draper NR, Smith H. Applied regression analysis, vol. 1. 2nded. (Прикладной регрессионный анализ,том 1, изд. 2), NewYork: JohnWiley&Sons; 1976.

[22] Williams EJ. Regression analysis. Sydney, New York, London: John Wiley & Sons; 1959.

[23] Electronic statistics textbook.<http://www.statsoft.com/texbook/stathome.html> [accessed 27.12.12].

[24] Laurent A, Etienne G. Experimental study of parameters influencing mechanical properties of hemp concretes. *Constr Build Materi* 2012;28: 50–56.

[25] Vėjelienė J, Gailius A, Vėjelis S, Vaitkus S, Balčiūnas G. Evaluation of Structure Influence on Thermal Conductivity of Thermal Insulating Materials from Renewable Resources. Materials Science (Medžiagotyra) 2011;17(2): 208-212.

[26] Stevulova N, Kidalova L, Junak J, Cigasova J, Terpakova E. Effect of hemp shive size on mechanical properties of lightweight fibrous composites. Procedia Eng 2012;42: 496-500.