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Physical-mechanical properties of Composites from Hemp Shives and Starch

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Abstract : *Currently, the main aim is to use as little fossil resources as possible by replacing them with natural renewable resources. Generally, for the production of building composite materials, cementitious binders or various synthetic resins from fossil resousces are used. Therefore, alternative raw materials for the production of ecological building materials must be looked for. Fibre hemp shives with a starch binder can be used in order to obtain ecological building material which is friendly to human healtth, produced from renewable resources, easily recyclable or utilized at the end of life cycle. This work presents the research of physical and mechanical properties of composites from fibre hemp and starch binder. Composites are produced from crushed hemp shives and different amounts of starch binder when thermal hardening regime is applied.*

Keywords –*hemp shives, starch, composite, thermal conductivity, compression, bending, tensile, short-term water absorption*

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I. INTRODUCTION

Traditional building materials are mainly produced from excavated fossil resources. Production process of such materials requires high energy consumption in terms of preparation of raw materials as well as final production. Taking into consideration the fact that Lithuania's excavated fossil resources are limited, and to reduce energy consumption during production, alternative solution could be the use of waste and renewable resources. One of the possible ways – wider application of vegetable based renewable resources.

Currently, fibre hemp crops area increase every year in Lithuania. Fibre hemp is agricultural annual plant which is characterised by high content of biomass. During fibre separation process, shives are obtained from stems. In order to use this vegetable based waste in the production of building materials, it is of great importance to investigate its properties, thus ensuring the proper selection of technological production factors as well as prediction of obtained product's properties.

For the obtaining the mixtures, various organic and inorganic binders may be used: clay dust, lime, cement, mixture of lime and cement, various resins, starch [1,2]. In early 90s, starch was started to be used in the production of bioplastics [3]. Together with plasticizer (water, glycerine, sorbitol), starch liquefies and melts at higher temperatures (90–180)ºC. This feature allows starch to be used in extruded bioplastics production [4]. Lots of studies have been conducted on composites for which production starch and various synthetic and natural fibers from renewable resources are used [3,5,6].

Bourdot et al. have tested composites from differently sized hemp shives and starch binder [7]. The obtained products are characterised by the compressive stress at 25% deformation varying from 0.57 MPa to 0.63 MPa, tensile strength – from 0.08 MPa to 0.11 MPa, Young's modulus – from 2.04 MPa to 2.47 MPa. Due to low density and high porosity (approx. 89%), the composites have excellent thermal insulating properties – thermal conductivity ranges from 0.0634 W/(m·K) to 0.0738 W/(m·K) at the average measurement temperature of 23°C. Le et al. have conducted a research of composites from different-fraction hemp shives and different amounts of wheat starch [8]. The obtained composites have the density ranging from 163.6 kg/m3 to 174.3 kg/m3, compressive strength at 5% deformation – from 0.014 MPa to 0.08 MPa, tensile strength – from 0.03 MPa to 0.13 MPa, Young's modulus – from 1.30 MPa to 2.04 MPa.

Because of the structure and chemical composition, hemp shives tend to absorb moisture and detain water in its structure. Research results have shown that composites from vegetable based raw materials absorb moisture from the environment what deteriorates thermal insulating properties of the products [9,10,11]. When hydrophobising additives are used, water absorption of composites from hemp shives may be reduced [12].

Composites produced from vegetable based raw materials are environmently friendly, easily recyclable or utilized. However, they are not resistant to fire impact; therefore, products of such type find their application in places that do not require conformation to strict fire safety standards [13]. Still, if fire retardants are used, flammability, combustibility and smoke release of the composites can be reduced [14,15].

II. MATERIALS AND METHODS

For the production of composites, crushed hemp shives, starch binder, hydrophobising additives and fire retardants were used. Crushed shives were obtained by milling 2.5/20 mm-sized shives particles with laboratory shredder (power of 1.1 kW, rotation speed of blades – 2800 rpm). After crushing, the size of obtained particles varied from 0.1 mm to 5.6 mm. Before crushing, hemp shives were soaked up in water for 2 hours. Corn starch was used as a binding material. The powders were of white colour, odourless, biodegradable and non-toxic (apparent density – 550 kg/m^3, pH 2–3). The corn starch was non-soluble in 20ºC and soluble in 90ºC temperature water.

The content of starch binder for the production of composites was calculated based on the amount of dry shives, and it was, respectively 0%, 10%, 20%, 30%, 40% and 50%. The chosen content was dozed into crushed shives, and the obtained mixture was mixed until homogeneous mass. The obtained forming mixture was poured into metal mould where semi-finished product with the preferred thickness was formed. Hardening procedure was carried out for 6 hours at 160°C temperature.

Thermal conductivity was determined according to EN 12667. The test was carried out with computerised heat flow meter LaserComp FOX 304. The measurement range of the apparatus (0.01–0.50) W/(m·K) and measurement accuracy ±1%. Three specimens with the size of (300×300×d) mm (d – the thickness of specimen, mm) were used to determine the parameter.

Compressive stress at 10% deformation of composites was determined in accordance with the requirements of EN 826, bending strength – EN 310, tensile strength – EN 319 with computerised laboratory testing machine HOUNSFIELD H10KS, maximal loading force – 10 kN, loading accuracy ±0.5% and loading speed accuracy ±0.05%. For compression and tension, three (50×50×d) mm-sized and for determination of bending strength – three (250×50×d) mm-sized specimens were used.

Short-term water absorption of composites was determined by soaking up the specimens in water for 24 hours according to EN 1609 (method A). Three specimens with the size of (50×50×d) mm were used. Short-term water absorption was calculated from the following equation (Eq. 1):

$$W_p = \frac{m_{24} - m_0}{A_p}, \qquad (1)$$

where W_p – short-term water absorption, kg/m^2; m_{24} – weight of the specimen after 24 hours in water, kg; m_0 – initial weight of the dry specimen, kg; A_p – area of a lower specimen's plane which is immersed in water, m^2.

Whereas the physical-mechanical properties of hemp shives composite depend on macrostructure, the macrostructure of representative hemp shives composite could be seen in Figure 1.

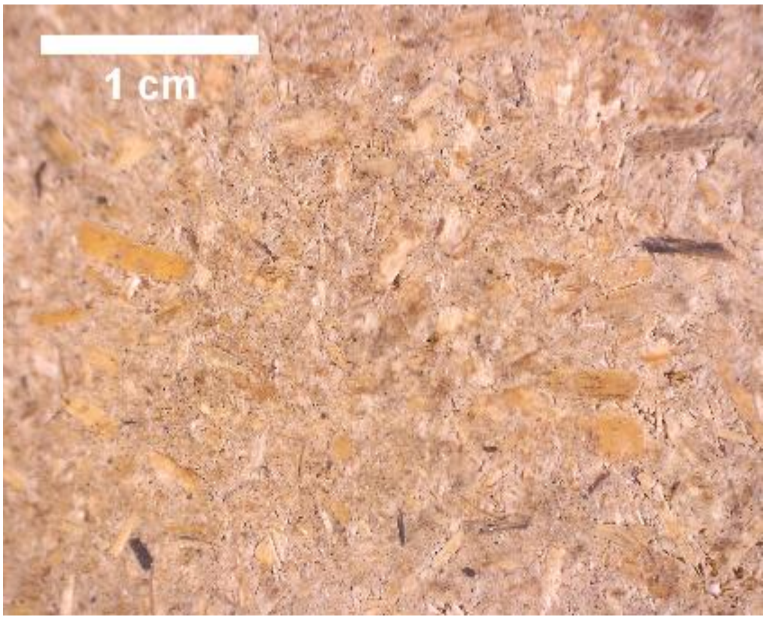


Fig. 1. The macrostructures of hemp shives composite with starch binder

Additionally, mathematical-statistical methods were used for evaluation of experimental data of hemp composites' physical-mechanical properties.

III. RESULTS AND DISCUSSION

For the determination of thermal conductivity, composites from crushed shives-fraction and different content of starch binding material have been formed. Figure 2 presents the impact of different starch content on composites' thermal conductivity. At the beginning of the test, control hemp shives composite without starch binder has been formed. After conducting thermal conductivity measurements of this type composite, its is determined that products are characterised by thermal conductivity with the average value equal to $\bar{\lambda}_{10^\circ C} = 0.0662 \frac{W}{(m \cdot K)}$ and standard deviation – $S_r = 0.000305 \frac{W}{(m \cdot K)}$. After addition of 10% of binder, thermal conductivity is $\bar{\lambda}_{10^\circ C} = 0.0665 \frac{W}{(m \cdot K)}$ and standard deviation – $S_r = 0.000305 \frac{W}{(m \cdot K)}$. When binder content is increased up to 20%, thermal conductivity is $\bar{\lambda}_{10^\circ C} = 0.0662 \frac{W}{(m \cdot K)}$ and standard deviation – $S_r = 0.000305 \frac{W}{(m \cdot K)}$. Introducing 30% of starch binder leads to products with thermal conductivity of $\bar{\lambda}_{10^\circ C} = 0.0654 \frac{W}{(m \cdot K)}$ and standard deviation – $S_r = 0.000305 \frac{W}{(m \cdot K)}$. Addition of binder content up to 40%, thermal conductivity value of composites makes up $\bar{\lambda}_{10^\circ C} = 0.0650 \frac{W}{(m \cdot K)}$ and standard deviation – $S_r = 0.000305 \frac{W}{(m \cdot K)}$. Under the starch content of 50%, thermal conductivity value is $\bar{\lambda}_{10^\circ C} = 0.0654 \frac{W}{(m \cdot K)}$ and standard deviation – $S_r = 0.000305 \frac{W}{(m \cdot K)}$. It can be assumed that the average thermal conductivity of formed hemp shives composites with different starch content (from 0% to 50%) is from the interval $0.0654 \le \bar{\lambda}_{10^\circ C} \le 0.066$.

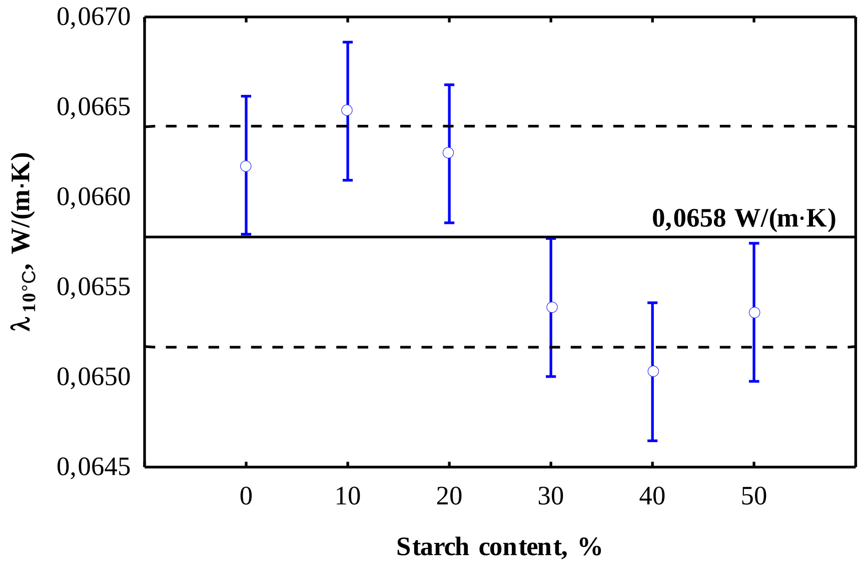


Fig. 2. Thermal conductivity of hemp shives composites from different starch content

The relationship between thermal conductivity, composite density and starch content has been as well evaluated. Tests results show that thermal conductivity based on density and different starch content may be approximated by the regression equation (Eq. 2) (Fig. 3, Table 1):

$$\bar{\lambda}_{10^\circ C} = b_0 + b_1 \cdot St + b_2 \cdot St^2 + b_3 \cdot \rho + b_4 \cdot \rho^2 + b_5 \cdot St \cdot \rho \quad (2)$$

where $\bar{\lambda}_{10^{\circ}C}$ – the average thermal conductivity value at the average temperature of 10°C, W/(m·K); St – starch content, %; ρ – composite density, kg/m^3; $b_0, b_1, b_2, b_3, b_4, b_5$ – constant coefficients.

Table. 1. Statistical data results for thermal conductivity of hemp shives composite

The number of test series n	Values of constant coefficients of equation (Eq. 2)						S_r, W(m·K)	$\eta^2_{\lambda\cdot St\cdot\rho}$
	b_0	b_1	b_2	b_3	b_4	b_5		
18	-0.0720	-0.6997·10^{-3}	-0.7857·10^{-6}	0.7729·10^{-3}	-0.1080·10^{-5}	0.1947·10^{-5}	0.000131	0.962

Based on conducted experimental research, relationship between thermal conductivity, density and starch content is determined. It can be approximated by the regression equation (Eq. 2) with the average standard deviation of 0.000131 W/(m·K) and determination coefficient 0.962. The obtained determination value shows that 96.2% of thermal conductivity $\bar{\lambda}_{10^{\circ}C}$ changes are caused by the variation in composite density and starch content.

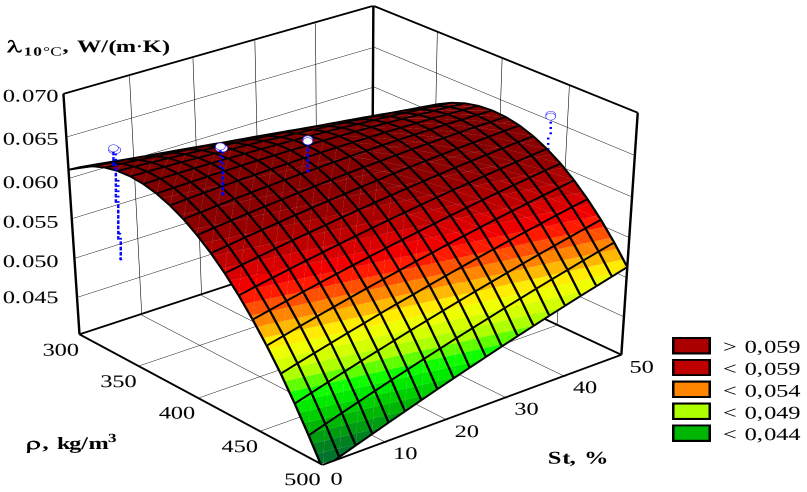
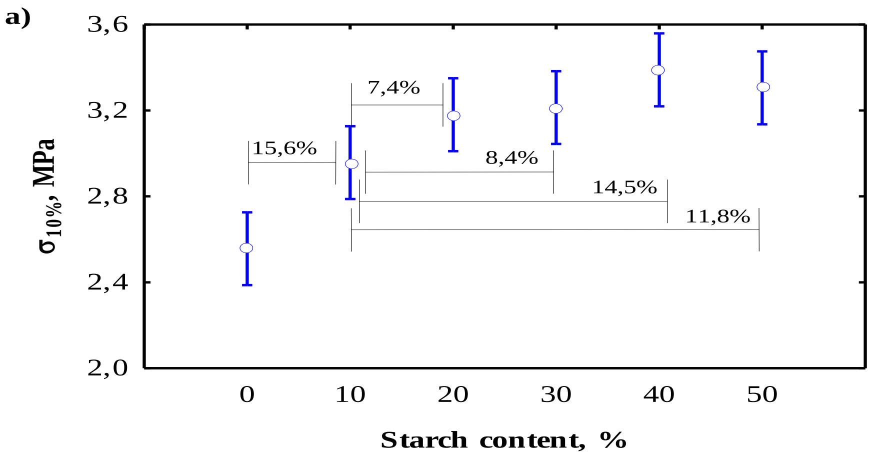


Fig. 3. Graphical representation of the regression Eq. (2) describing the dependence of the thermal conductivity values $\bar{\lambda}_{10^{\circ}C}, \frac{W}{(m\cdot K)}$ on the values of $\rho, \frac{kg}{m^3}$ and St, %

Figure 4 shows experimental results for mechanical properties of composites from different content binder.



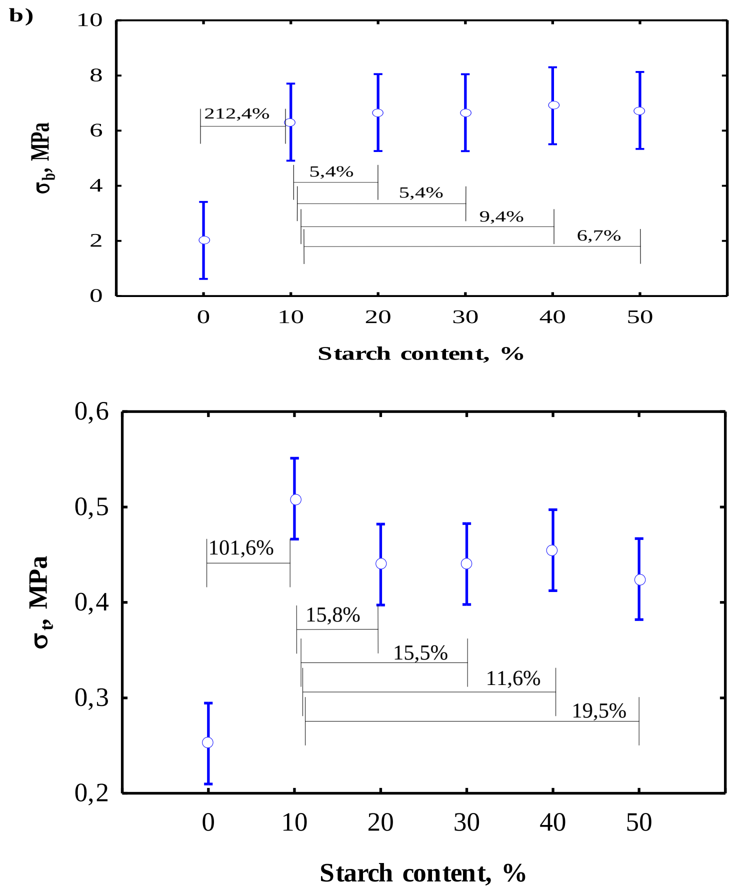


Fig. 4. Mechanical properties of hemp shives composites: a) compressive stress; b) bending strength; c) tensile strength

Figure 4a presents the relationship between compressive stress and starch content. Compressive stress $\overline{\sigma}_{10\%}$ for composites, which are formed from crushed hemp shives and 10% of starch increases by 15.6%. Its average value varies from 2.56 MPa to 2.96 MPa ($S_r = 0.128$ MPa and $S_r = 0.187$ MPa). Addition of starch from 10% to 50% allows obtaining composites with by 11.8% increased compressive stress $\overline{\sigma}_{10\%}$ with the average value equal to 3.31 MPa and standard deviation $S_r = 0.0508$ MPa.

Figure 4b shows the relationship between bending strength and starch content. Average value of bending strength for hemp shives composite without starch binder is $\sigma_b = 2.02$ MPa and standard deviation – $S_{\sigma_b} = 1.11$ MPa. The addition of 10% of starch allows obtaining composite with the average bending strength equal to $\sigma_b = 6.31$ MPa and standard deviation $S_{\sigma_b} = 1.11$ MPa, i. e. the increment makes up 212.4%. Compared hemp shives composites with 10% and 50% starch, the increment of bending starch is only 6.7%, and the average value is $\sigma_b = 6.73$ MPa with standard deviation $S_{\sigma_b} = 1.11$ MPa.

The graphical interpretation of tensile strength dependence on starch content can be observed from Figure 4c. Experimental tests results show that the average value of tensile strength for composite without binding material is $\sigma_t = 0.252$ MPa (standard deviation $S_{\sigma_b} = 0.0337$ MPa). After addition of 10% of starch, the value of tensile strength increases approx. by 101.6%, and the average value of tensile strength is $\sigma_b = 0.508$ (standard deviation $S_{\sigma_b} = 0.0337$ MPa). It can be stated that increasing content of starch binder from 20% to 50%, increases the average value of tensile strength by 15.4% compared to composite with 10% of starch. Therefore, the average value of tensile strength is $\sigma_t = 0.440$ MPa (standard deviation $S_{\sigma_b} = 0.0309$ MPa). It may be assumed that the highest improvement in strength properties of hemp shives composites is when 10% of starch is used.

Figure 5 presents graphical interpretation of different starch content impact on short-term water absorption of hemp shives composites. After conducting the measurements of short-term water absorption, it is determined that 10% of starch binder reduce water absorption value by approx. 8.9%. The parameter ranges from $\overline{W}_p = 5.40\frac{kg}{m^2}$ (standard deviation $S_{W_p} = 0.221\frac{kg}{m^2}$) to $\overline{W}_p = 4.96\frac{kg}{m^2}$ (standard deviation $S_{W_p} = 0.221\frac{kg}{m^2}$). Furthermore, increasing amount of starch binder from 10% to 50% reduces short-term water absorption by 4.6%. The value varies from $\overline{W}_p = 4.96\frac{kg}{m^2}$ (standard deviation $S_{W_p} = 0.221\frac{kg}{m^2}$) to $\overline{W}_p = 4.74\frac{kg}{m^2}$ (standard deviation $S_{W_p} = 0.221\frac{kg}{m^2}$).

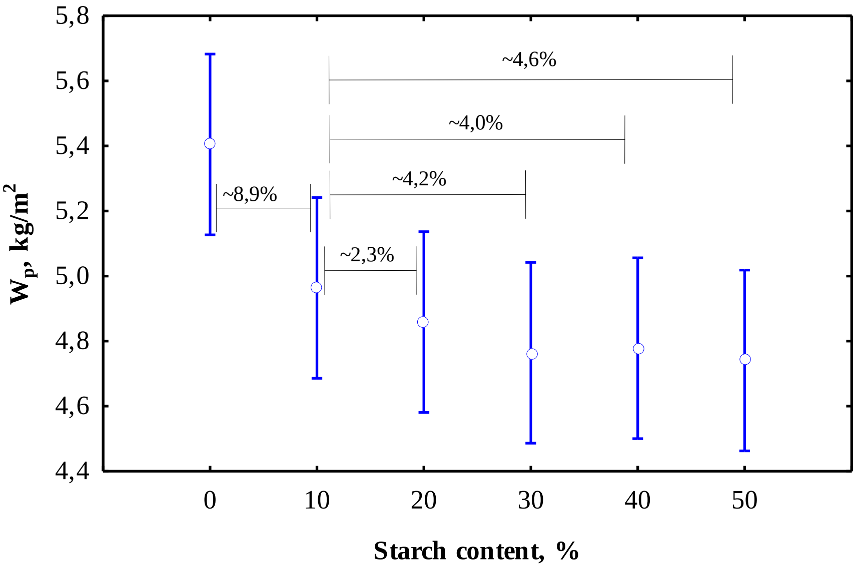


Fig. 5. Short-term water absorption of hemp shives composites

It can be concluded that the greatest reduction of short-term water absorption value is observed when 10% of starch binder is used. In order to reduce negative impact of water on the properties of composites, hydrophobising additives should be used.

Comparing our results and Bourdot et al., it is observed that the difference between the values of thermal conductivity is 1.05 times. The difference between the values of compressive stress is ~5 times, and the difference between the bending strength is 32 times. Such disagreement could be attributed to the type of composites production, preparation of raw materials, thermal processing and different densities of the composites.

IV. CONCLUSION

At the amount of starch from 0% to 10%, thermal conductivity of composites from crushed hemp shives varies from 0.0662 W/(m·K) to 0.0665 W/(m·K), compressive stress – from 2.56 MPa to 2.96 MPa, bending strength – from 2.02 MPa to 6.31 MPa, tensile strength – from 0.252 MPa to 0.508 MPa and short-term water absorption – from 5.40 kg/m^2 to 4.96 kg/m^2. Increasing amount of starch binder up to 50% allows obtaining composites with thermal conductivity of 0.0654 W/(m·K), compressive stress up to 3.31 MPa, bending strength up to 6.73 MPa, tensile strength up to 0.425 MPa and short-term water absorption up to 4.74 kg/m^2.

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