Application of Peat, Wood Processing and Agricultural Industry By-products in Producing the Insulating Building Materials

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Abstract. One of the most important problems nowadays is energy efficiency securing. In the present paper thermal insulation materials were designed, their mechanical and insulation properties were optimized. Special attention is paid to the peat, wood processing industry and agricultural by-products which are used in composite production. The activation of the raw materials allows not only to improve existing properties and open the new ones but also to make greater use of natural resources. Variety of the insulation materials was obtained using peat glue as binder and using different fractions of the wood chips, peat and hemp as fillers. For obtaining the peat binder, mechanically-thermal activation was applied using planetary ball mill in the water environment. During the research various insulation building materials were obtained: peat glue was used as a binder and various fraction wood chips, hemp sheaves and peat – as filler. The obtained materials and products are:

- The activated peat that can be used as a binder,
- Peat-Wood/Hemp insulation panels with density 150–300 kg/m^3, thermal conductivity from 0.050 to 0.065 W/ mK;
- Peat-Wood/Hemp composite with resistance to compression of 1 MPa.

Keywords: *peat, composites, ecological materials, insulation materials.*

1. Introduction

Growing economy and increased public welfare level demand a lot of energy and with it associated consumption of primary energy resources which lead to serious problems including depletion of primary energy resource stock, also environment pollution, thus facilitating the irreversible climate changes in the Earth's atmosphere. With continuous energy price increase and necessity of energy supply in the future as well as considering the need of refusing of the emission of gases which facilitate greenhouse effect it is necessary to apply efforts to provide suitable levels of energy efficiency which in turn would lead to reduce of energy resource consumption. Buildings construction and maintenance are responsible for 40 % of energy consumption and 36 % of CO_2 emissions in the European Union. Improving the energy performance of buildings is therefore critical for achieving the EU's climate and energy objectives (Europe 2020): a reduction of 20 % of greenhouse gases emissions, a share of 20 % renewable and 20 % energy savings, all to be achieved by 2020 (Directive 2010/31/EU, 2010; University of the West of England, 2011).

In comparison to other EU member countries Latvia has the lowest quality of residential buildings which are relatively old and have low heat retention. 71 % of the total amount of residential buildings in Latvia has been constructed by using such construction materials in external enclosing structures that do not comply with today's thermal and environmental requirements and that result great heat energy consumption between 150–350 kWh/m^2 per year (Annex No. 7 – Energetic' development guidelines for 2007–2016). Thus, considering the above discussed information, the Energetic development guidelines of Latvia for the years 2007–2016 plan to implement energy efficiency measures in the consumer sector including a set goal to reduce the mean specific thermal energy consumption in buildings 195 kWh/m^2 by the year 2016 which may be accomplished by implementing a complex of measures. The biggest contribution shall be gained from the heat insulation of the building, thus reducing thermal energy consumption, CO_2 emission and pollutant release into the atmosphere.

In order to improve total energy efficiency the use of effective heat insulation materials produced with local raw materials may positively affect domestic economic development. While reviewing such raw materials and resources in Latvia which potentially could be used for heat insulation materials production, there should be focus on peat as well as on the wood-processing and agriculture by-products.

Peat is a renewable resource, continuing to accumulate on 60 % of global peatlands. However, the volume of global peatlands has been decreasing at a rate of 0.05 % annually owing to harvesting and land development. Many countries evaluate peat resources based on volume or area because the variations in densities and thickness of peat deposits make it difficult to estimate tonnage. World total mine production in 2011 was 22 million tonnes and the biggest producers from the countries were Finland – 4,8 million tonnes, Ireland – 3,3 million tonnes, Belarus – 3,2 million tonnes, Sweden – 2,5 million tonnes, Russia – 1,6 million tonnes, Latvia – 1 million tonnes etc.). World reserves of peat in 2011 is 10 billion tonnes and are estimated based on data from International Peat Society publications and the percentage of peat resources available for peat extraction (the biggest peatland owners are Finland with 6 billion tonnes and Russia with 1 billion tonnes (Latvia – 76 million tonnes) (USGS, 2012).

The total amount of available peat resources may not be determined definitely due to multiple reasons, not only because the formation of peat and bogs is a continuous process but also due to varying definitions of peat deposits. In Latvia the minimum of peat level in bogs is 30 cm, if such layer is thinner, the area is considered a wetland. However, the thickness of peat layer line with the definition of a peatbog is determined in equal manner. For instance, in Ireland the thickness of peat layer in non-drained territories is 45 cm (Poulin et al. 2004, Hammond 1981), but in drained territories – 30 cm, in Germany – 20 cm (Xuehui and Jinming 2009) but in the United Kingdom it has to be at least 50 cm (Nayak et al. 2008). In essence, any territory with elevated levels of moisture content may be considered as a bog, if peat formation process takes place in such area or if such area bears vegetation that is typical to a bog, it is considered, that 5 cm peat layer is enough to start developing of typical to the peatlands vegetation process (Silamiķele 2010). Considering the fact that global research on total amount of resources in Latvia were conducted 30 years ago and more recent studies reflect only selected data, the present article contains data from the year 1980. Nevertheless, also in the older studies, the total amount of resources differs, for example the total area of swamps in Latvia constitute around 10 % of the total territory of the country, such deposits may hold up to 11.3 billion m^3 or 1.7 billion of ton, according to Peat Fund in 1980. The chemical variety of peat indicates the potential of the resource, but in the meantime it restricts one to develop a homogenous technology for production of peat base heat insulation materials. In spite of various peats' advantages – it is mostly uses in two ways – in farming and as a combustible.

As to the peat usage in the Europe where peatbogs occupy approximately 956949 km^2 of territory in Europe it has been used not only for heat supply but also as an insulating material and moisture regulator in its natural state or as a loose material, granules, maths or boards. In the past it has been used in Germany, Ireland, Scandinavia and Scotland. Today, insulation products of peat are again being produced in Sweden (Berge 2001). Not only in Europe, but also in the United States of America, peat is widely used not only as the fertilizer, but also in the manufacturing of heat insulation plates from dried peat (McFadden *et al.* 1991). In the United States, the short-term outlook is for production to average about 600,000 tons per year and imported peat from Canada to account for more than 60 % of domestic consumption (USGS, 2012).

New types of peat usage may be found by peat activation which improves the existing features of the materials and reveals new ones. It is possible to influence on the specific properties of raw materials by using various types and modes of activation. The activation of raw materials not only opens new possibilities in terms of use of such materials, but also allows using them more efficiently.

Mechanically-thermal activation of peat in the planetary ball mill in the water environment was used to obtain peat binder. Such binding agent is ecologically clean and environmentally friendly which is especially important considering the current binding agents available in the heat insulation materials in the market. The extraction of peat binding agent may be implemented not only by activating in planetary ball mills, but also via the use of cavitations' device (Цыфанский 2008).

Within the research were obtained various insulation building materials: peat glue was used as a binder and wood processing waste (various fraction wood chips), agricultural waste (hemp sheaves) and peat – as filler, which is *not only technically*, *but also economically* more beneficial solution thus the high likeliness of natural raw materials and the low density allows one to produce efficient heat insulation materials. (Томсон and Наумова 2009). Upon reviewing the information available in literature, composites have been also created in the course of studies conducted by the Scientific construction materials institute of Russia, where a previously mechanically activated peat was used as a binding agent component and planer chips due to the fact that wood is a porous material. (Копаница et al. 2009). As a result of the research it was found that chemically mechanic activation facilitates an intensive reaction between urea and the hydroxide in peat, as well as between the functional carbonyl groups and polysaccharide. It must be noted that the biggest effect was achieved only with high grade peat because it is more saturated with organic compounds any may form various chemical bonds with introduced modifiers. (Саркисов et al. 2008).

Thus by the use of wood filler at a rational grading composition content in the research in Russia, a peat – wood composite was obtained by using a foam forming additive "Neopor" reducing the value of thermal conductivity down to 0.04 W/mK, when the least value with „ TEAC" is

0.05 W/mK with density of 170 kg/m^3, but peat – wood composite without adding a foam forming additive has the value of thermal conductivity 0.067–0.070 W/mK (Копаница et al. 2009). Considering the fact that one of the most significant drawbacks is the low water resistance, such resistance was improved by introducing hydrophobisators, in the presence of such water absorption was significantly reduced, for example, by introducing a hydrophobisators in a peat – wood composite of “Аквасил”, which was based on potassium metylsilicate, the mean water absorption value (according to mass) was reduced to 40 %, but the value of thermal conductivity – 0.04 W/mK, density – 270 kg/m^3, compressive strength – 0.53 MPa, bending strength – 0.33 MPa and water absorption – 40 %. (Копаница and Калашникова, 2007).

In present research peat utilization opportunities in the area of heat insulation material production in Latvia by referring the foreign experience are described. Within the research peat composites have been produced, their application properties have been enhanced by various peat activation methods.

2. Methods

During the experiments the following types of the natural wet peat were used:

1. High type peat with pH = 3.2 – 4.5 (Jelgava region, Livberze parish).
2. Transition type peat with pH = 4.5 – 5.5 (Madona region).
3. Low type peat with pH = 5.5 – 6.5 (Kraslava region, Robeznieki parish).
4. Low type peat with pH = 6.5 – 8.0 (Kraslava region).

Two types of wood chips were selected as fillers for production of peat – wood composite materials: 15 mm long and up to 0.2 mm thick in diameter birch fibers (also known as wood wool fibers) and wood chips from coniferous trees which were up to 30 mm long and up to 0.6 mm thick with moisture content of 12 %.

Up to 40 mm long hemp sheaves (USO–31) were used as fillers for production of peat – hemp composites.

Peat was activated in RETSCH PM 400 planetary ball mill. The initial moisture content of the raw material was 270 %, but due to practical reasons, it was increased up to 380–400 % in order to enable easy removal of the peat from containers. To assess the activation effect of the peat, it was chosen to perform a bending test on the peat – wood composite. 12 prisms of the materials with equal content of activated peat and wood chips were produced. The following mechanically thermal activation times were selected: 30, 60, 90, 120, 150 and 180 minutes.

The experiment was divided in two parts: first stage involved 30 to 90 minutes long activation periods and in second stage the activation periods were increased from 120 to 180 minutes. Mix compositions and hardening conditions of the produced samples remained unchanged. The mechanical testing of the first stage was carried out for 2 days old samples, but in the second stage – at the age of three days (with an additional 24 compulsory drying at a temperature of 75 ºC).

Mixing of wood-processing by-products in a form of activated peat mass and filler was performed manually until a uniform mass was achieved, when filler is being fully covered with the activated peat (Toropovs 2012). An optimal relation of the activated peat and filler was defined practically based on the type of the filler used. During the mixing of the mass, it was not only necessary to obtain uniform color but also to restrict the distribution of the excessive water in the composite mass.

Two different composite mixes laying and loading modes were used during the production of samples:

- without additional compression in the moulds;
- with additional temporary compression under 0.05 MPa high pressure.

Thus it was possible to obtain a more dense composite material structure and higher mechanical strength. As well as it was possible to minimize final product shrinkage, to prevent formation of shrinkage cracks in the case of usage of fine filler.

Metal mould with dimension of 30 x 30 cm (with adjustable height) was used for plate production. The bottom part of the mould and its lid was made from perforated metal sheets which improve the sample production process, in case if an additional compression is required and there is a presence of high water content – it allows drain excessive water. The curing of peat plates was implemented without removing the sample from the mould, thus allowing preventing deformation and retaining the smoothness of the surfaces. According to investigations made before by other researchers (Копаница and Калашникова 2007) the compulsory curing of the samples was selected at a temperature of 75 °C for 24 hours.

Specially prepared samples (4 x 4 x 16 cm) were used for mechanical testing (see Fig. 1). The sample bending and compression tests (see Fig. 2 and 3.) were performed with the use of ZWICK Z100 perpendicular to the formation direction of the samples, thus providing the establishment of mean strength in cross section, reducing the influence of certain weakening, which could have formed while samples were removed from moulds and a non-homogenous structural density in the direction of cross-section formation.

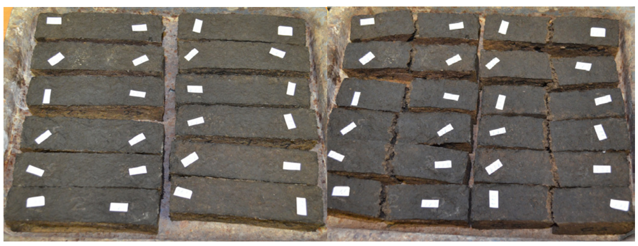

Fig. 1. *Peat composite material specimens before (left) and after (right) bending test*

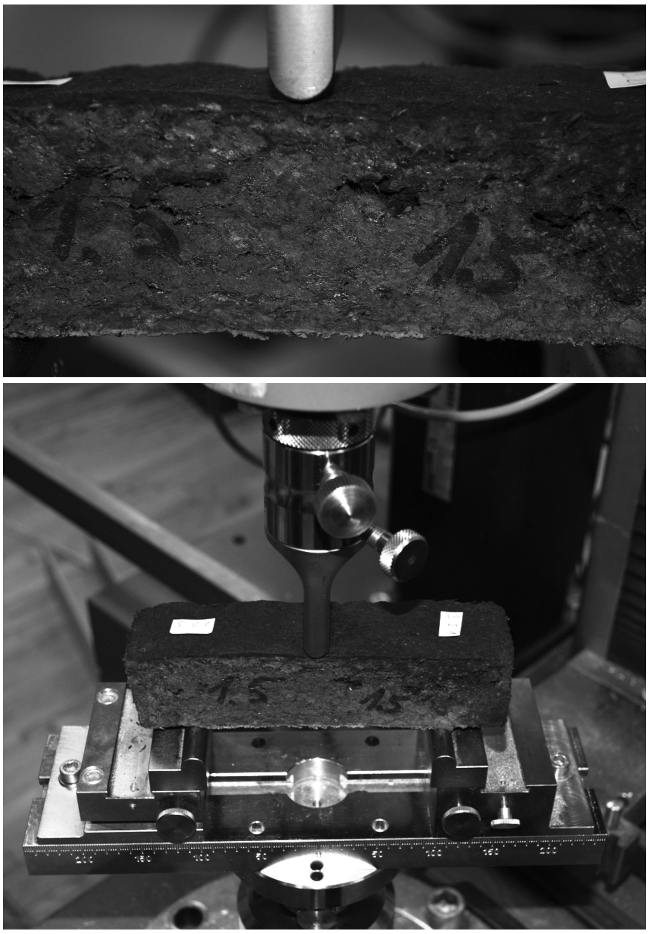

Fig. 2. Bending test of peat composite material specimen

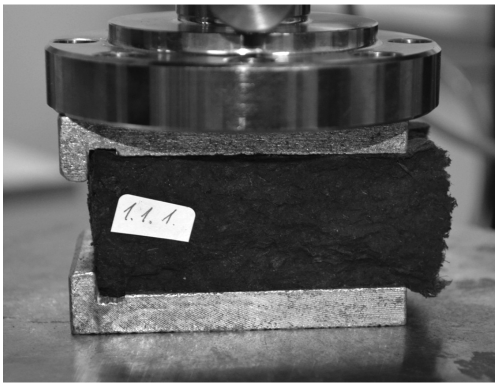

Fig. 3. Compression test of peat composite material specimen

3. Results

Within the present investigation a homogenous activated peat mass with binding agent properties was obtained. No segmentation or other visual changes were observed by containing a mass of activated for 30 minutes period peat in a sealed container for 10 days. By keeping the peat during one year, a small layer of water was observed on the top (up to 0.5 mm), but in general the mass maintained its homogenous properties. The ecologically obtained, clean peat binding agent was used to produce a peat-woodchip/hemp composite material.

The obtained composite materials were subjected to compression strength and heat conductivity tests in accordance with previously described methodology. The effect of peat activation duration on the strength of the peat-woodchip composite material was verified and summarized in table 1.

Table 1. *Influence of peat activation time on peat-wood composite material bending and compressive strength*

	Activation time of peat mix					
	30[1]	**60[1]**	**90[1]**	**120[2]**	**150[2]**	**180[2]**
Average bending strength of peat-wood composite material samples in the case of 10 % deformation, MPa	0.046	0.050	0.048	0.067	0.065	0.027
Average compressive strength of peat-wood composite material samples in the case of 10 % deformation, MPa	1.295	1.317	1.081	1.012	0.738	0.739

[1] – 1st mix phase

[2] – 2nd mix phase

The heat conductivity factor of composite peat – wood material plate (see Fig. 4) was determined depending on the moisture content of the product (see Fig. 5).

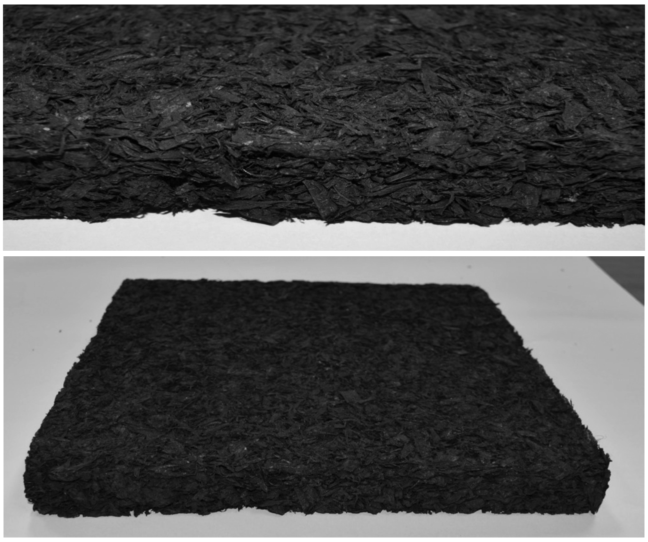

Fig. 4. *Composite peat-wood material plate with density 260 kg/m^3*

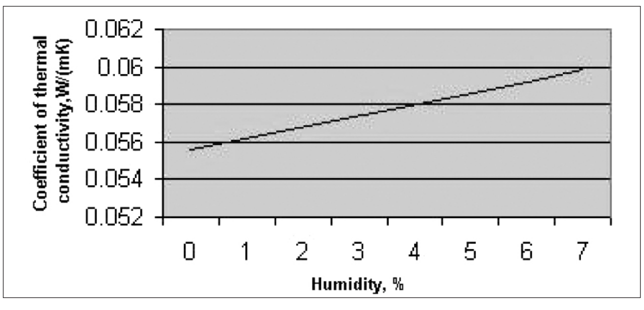

Fig. 5. *The influence of humidity on the thermal conductivity coefficients of peat-wood composite material*

Peat – hemp composite samples were produced with a peat and water mass ration of 1:1.5; 1:2 and 1:2.8 in order to identify the optimum amount of water, obtaining a peat binding agent with high adhesion qualities with peat and hemp sheaves, in the meantime not increasing the shrinkage and not reducing the material strength to any significant extent, thus the samples were not easily deformed. The mean density of the obtained samples (kg/m^3) depending on the type of the peat and the water ratio is summarized in table 2.

Table 2. *Density (kg/m³) of the peat samples depending on its type and water volume*

Proportion of peat and water	Type of peat			
	1	2	3	4
1:1.5	302.4	301.2	300.6	300.7
1:2.0	289.2	289.0	286.8	286.8
1:2.8	275.3	275.6	275.4	274.3

It was required to dry the samples with peat and water proportion of 1:2 and 1:2.8 for 1 to 2 hours longer during the experiment. If the amount of water was reduced, the blending of peat suspension with hemp sheaves became more difficult and time-consuming, but the material itself was formed with more even surface and unites joining better filler elements between each other.

To improve the properties of peat – hemp composite, for the purposes of further research, a water ratio 1:1.6–1:1.7 and 20 % of hemp sheaves was selected, thus obtaining samples with a density that does not exceed 240 kg/m^3, and the heat conductivity factor of which is 0.056 – 0.060 W/mK.

4. Discussion

The results accomplished in the research provide an insight in the high technological use opportunities of the peat found in Latvia, including such application as construction and heat insulation composite materials in a form of a binding agent.

The obtaining of a homogenous activated mass of peat indicates towards the excellent storage and transportation opportunities of such binding agent, which is important for industrial manufacturing activities. A sample of an activated peat mass contained for 1 year exhibited minimum segregation and additional smell, mix is not distinguish from freshly activated peat, thus indicating absent of biological processes taking place during the storage of peat. The further study must identify the effect of the processes on the binding agent properties of an activated peat in short term which would have a crucial role in case of industrial manufacturing, transportation and storage.

The size precision of the production by applying an additional pressure during the formation of the samples is sufficient in case of plate and pipe heat insulation material production.

According to the conducted research, the increase of peat activation duration improves the compression strength of composite material. The observed increasing of compression strength was in the accordance with the results, obtained by other researchers. Considering the relatively low number of samples that were used to determine the mechanical strength of the composite material and the performance of the test in two stages, for the purposes of a more accurate, it may be useful to increase the number of samples for each content ratios and to find the mechanical properties changes per specific content based on the total hardening duration, on separate basis also considering the effect of the additional thermal processing on strength of the composite in the event of changes concerning the technological stage of sample curing.

The mechanical properties of the obtained material indicate towards its possible usage in self load-bearing structures, and in the case of improving the mechanical properties of the material in further, it may be used for low story load-bearing structures.

The heat conductivity of the composite materials is sufficient for its use for heat insulation purposes. Use of such heat insulation would not only ensure the energy efficiency of the building but would also allow finding additional use of the by-products resulting from wood-processing and farming currently being used in filling agent.

The almost linear heat conductivity factor increase within margins of low material moisture content allows forecasting its heat insulation features in structures. The thermal properties of the obtained composite material (thermal conductivity coefficient 0.056–0.060 W/(m·K)) enables it compete with commonly available heat insulation material (foam polystyrene and stone wool, having heat transmission coefficient app. 0.04).

It shall be useful to determine the dependence of mechanical strength of the material on the moisture content in the future research.

Produced peat-woodchip/hemp composite material is 100 % recyclable and after recycling it can be used as a filling agent for production of similar materials.

A wide use of the obtained material produced fully with locally extracted raw materials, allows solving building and structure energy efficiency issues with the use internal resources of the Baltic States which would generate additional employment and facilitate economic growth.

5. Conclusions

Within the experimental work a set of heat insulation materials have been obtained where peat glue has been used as a binding agent. Peat activation allowed obtaining material with properties of a binding agent which is environmentally safe.

Peat activation period affects the properties of the binding agent in the obtained mix of peat, upon increasing the time of activation the mechanical properties of peat-woodchip composite materials are increasing.

The obtained physical-mechanical properties of peat-woodchip composite materials allow competing with the heat insulation materials available in the market.

The applied technologies enable a better utilization of natural resources. Production compulsory drying technological cycle is twice shorter in comparison with the current commonly used peat heat insulation material production related technology as well as at a lower maximum temperature which in turn reduces the energy capacity of the process.

The obtained material may be widely used for ecological construction as a heat insulation material. These materials are air permeable; the peat may absorb unpleasant smells and form an anti-bacterial environment.

All used raw materials are local and commonly used which in terms of material production shall facilitate the development of national economy.

The use of such material shall enable to solve building energy efficiency problems by using only domestic resources.

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