Research of pressed thermal insulation materials, based on organic waste

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Abstract. Issues of obtaining heat-insulating products, based on flax waste, are discussed in the article. The main technologies for the materials production, based on plant materials and organic waste are determined on the basis of the references data. The possibility of flax waste using as filler for pressed building materials have been determined. The composition and properties of the organic filler - flax waste, the main binding components have been determined. Optimal ratios selection of flax and binders was made, obtaining pressed materials. It is shown that the formation of the heat-insulating material structure is influenced by the granulometric composition of the organic filler. Two-way analysis of variance was carried out in order to determine this effect. Technological parameters of pressing process and optimal hardening mode have been determined. A technological scheme for the pressed plate’s production, based on flax waste, has been developed.

1. Page layout
The production and use of building materials, based on plant materials and organic waste has been known for a long time. Fiberboard and chipboard, stramite, peat slabs, arbolite, fibrolite, reeds, cork insulation are the most famous materials. Such materials are characterized by high thermal performance, in addition, from an environmental point of view, a waste disposal problem and efficient processing of raw materials is solved, and it also becomes possible to obtain environmentally friendly building materials.

The main components of thermal insulation products based on plant waste are a binder, organic filler, and various corrective additives (antiseptics and fire retardants). Various resins, polyvinyl acetate emulsion, synthetic latexes and others are used as organic binders. Liquid glass, cement, gypsum, ash and others are used as mineral binders.

The study of technological and thermophysical properties of plant origin aggregates is the subject of such works as V.I. Bukharkina, Yu.P. Gorlova V.M. Kurdyumova, I.Kh. Nanazashvili, B.N. Ponamarenko, I.A. Ryb'eva, N.I. Sklizkova, V.M. Khruleva, V.G. Khozina, S.A. Ugryumov and others [1-5]. A number of publications present comparative data on the organic fillers’ properties [6-10]. The possibilities of using plant raw materials in the technology of building materials are considered in [11], and methods for obtaining plant building materials from wood waste and other plant waste (buckwheat husks, sunflower husks, flax fires) with the use of a "steam explosion", are proposed. These developments are based on the "steam-explosive" processing technology of wood chips, which allows changing the morphology of wood and affecting its chemical composition. The authors [12] proposed a technology for structural wood concrete, made of crushed cotton stalks and
sludge waste from asbestos-cement production. The authors [13] have developed a heat-insulating material, based on fibrous filler and silica sols (high-modulus liquid glasses). At the same time, a method for obtaining a material of the "structure in structure" type was proposed, so, a combination of a relatively coarse chaotic frame made of straw pieces with communicating large cells (0.5 - 1 sm in size) and a fine-fiber component (pores less than 1 mm) - wool waste from fur production.

Foreign experience in the use of plant raw materials and organic waste includes such materials as Dyurizol (Switzerland), which represents the use of wood-concrete blocks of fixed formwork in low-rise construction. Chip-cement boards VELOX (Austria), which are made of spruce chips on a cement binder and mineral additives. STEICO (Germany) heat-insulating material is made of straw and wood. Werzalit (Germany) is hot-pressed wood-polymer composite, containing 75% wood and 25% polymer resin. This technology makes the material durable and resistant to various influences [14].

We should conclude, based on the literature data, that the building materials production on plant materials and organic waste is carried out according to the following technologies: materials production on flax waste without a binder, but, disadvantage of this method is high energy consumption; plates production from waste using phenol-formaldehyde and urea-formaldehyde resins as binders, so, the disadvantage is harmful substances releasing into the environment by materials.

Currently, building materials, based on plant raw resources (peat, reeds, etc.) cannot be classified as promising insulating ones due to such disadvantages as flammability, insufficient water and biological resistance. It is also worth noting that organic fillers release easily hydrolyzable substances, and even if easily removable substances are excluded, the strength of the materials increases slightly. Weak adhesion of organic raw materials with cement binder and high stability of physicochemical parameters of plant raw materials and organic waste, allows the use of materials only in temporary buildings and structures.

According to the analysis of the obtaining heat-insulating products’ problem, based on plant raw materials and organic waste, the goal of the study was to obtain a pressed heat-insulating material on agricultural waste - flax waste and a complex modifier. It is necessary to solve a number of problems in order to achieve the intended goal: to determine the composition and properties of organic filler - flax waste; to make the optimal selection ratio of flax fire and complex modifier, obtaining pressed materials; to investigate physicochemical processes and structure formation in kostrolite materials.

2. Materials and Methods
Flax waste has the following specific properties, in contrast to the traditionally used wood raw material (sawdust, crushed chips, and shavings): low moisture swelling, not exceeding 2%, a significant content of lignin in the organic part up to 46%.

The content of the easily hydrolyzable part (hemicellulose) in the waste is much less than in wood, so the use of waste in the production of slabs with mineral binders is quite justified for example in cement. In this case, the effect of the so-called "cement poisons" on the structure formation process of the material is significantly reduced, and the physical and mechanical properties of the products increase.

The granulometric composition of the vegetable aggregate was established according to the indices of partial residues on standard sieves used in the concrete aggregates analysis. Particles with a size less than 5 mm prevail in the flax bulk sample. Coarse fractions over 10 mm contain up to 12-15%. The yield of the 5 / 2.5 mm fraction at the flax campfire is about 62%, which makes it possible to use it in the pressed production without additional processing [15].

Water extract was prepared with a solid component to distilled water ratio of 1: 5 by weight to determine the hydrogen index of flax waste. The hydrogen index of the flax waste was determined on a pH-340 device and is 6.35 units.

The initial moisture content of waste is from 12% to 30% coming from the flax processing plants, which makes it possible to reduce drying costs in comparison with the production of particle boards. The advantage of fibrous materials, made from flax waste, is short drying and aging.
In the experimental compositions, liquid sodium glass $\text{R}_2\text{O} \cdot n\text{SiO}_2$ was used as a binder with a silicate modulus of 3.25-3.30 and a density of 1.47 g / sm$^3$. The hydrogen index is 13 units. The relative viscosity according to the VS-4 viscometer is 35-37 seconds.

In order to ensure the structural strength of molding materials and the strength of finished pressed heat-insulating products, polymer additives (styrene-butadiene latex, polyvinyl acetate emulsion (PAE) were studied as a binder. The choice of these materials was due to the fact that they have good mechanical, chemical resistance, and their films have a high adhesion capacity in relation to flax.

Styrene-butadiene latex is a deep polymerization product of divinyl and styrene (35:65 parts by weight) in an aqueous emulsion with density of 1.02 g / sm$^3$, relative viscosity of 8-10 sec., dry residue content of 47-48%, $\text{pH} = 11.5$. It is not explosive and it does not spontaneously ignite. It does not burn and it does not emit hydrocarbons in quantities sufficient to form flammable and explosive mixtures.

Polyvinyl acetate emulsion contains up to 58% resin. It is obtained by polymerization of vinyl acetate in the peroxides presence by the emulsion method with density of 1.45 g / sm$^3$, relative viscosity 90-95 sec., dry residue 49-49.5%, $\text{pH} = 10.9$. The positive properties include good adhesion and abrasion resistance, negative - reduced water resistance [16-19].

3. Results
The content of flax reaches 65-70% in the composition of pressed heat-insulating materials. The selection of compositions was carried out for kostrolite mixtures, based on organic (synthetic latex, polyvinyl acetate emulsion) and mineral (liquid sodium glass) binders. The optimum ratio of the components was set according to the average density, thermal conductivity, and strength.

The main binding component of the mixture was sodium hydroxide glass. It allowed you to ensure the incombustibility and biostability of materials.

The hydrogen index ($\text{pH}$) of the water extract from flax waste mass, based on water glass was 10.9 units. Organic binders, styrene-butadiene latex and polyvinyl acetate emulsion were also investigated. The hydrogen parameters of the water extract from the flax waste mass and polymer binders - latex and polyvinyl acetate emulsion 6.7 and 6.4, respectively.

The influence of organic and inorganic binders on the samples properties was determined (table 1).

| Composition          | Average density kg / m$^3$ ($\rho_m$) | Flexural strength, MPa (Rflexural) | Compressive strength, MPa (Rcomp) | Water absorption volume ratio, % for 24 hours (W) | Heat water content, W / (m$^3$$C$) (λ) |
|----------------------|--------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------------------|---------------------------------|
| Fire waste, liquid glass, water | 240                                 | 0.68                              | 0.52                              | 54.5                                          | 0.053                           |
| Fire waste, PAE, water          | 290                                 | 1.14                              | 0.87                              | 43.6                                          | 0.067                           |
| Campfire flax, latex, water     | 265                                 | .09                               | 0.72                              | 28.2                                          | 0.061                           |

Water glass samples have the lowest average density of 240 kg / m$^3$, but the compressive and flexural strength values are 0.52 and 0.68 MPa, respectively. Bonfire flax compositions and PAE allow obtaining samples with an average density of up to 290 kg / m$^3$, providing good strength characteristics. The density of the samples is 265 kg / m$^3$, and the strength and water resistance indicators increase with styrene-butadiene latex addition.

The amount of binder in the solution was varied in order to achieve complete wetting of the fiber bonfire flax surface, which helps to increase the adhesion between fibers and binder. The density of the material increases, as the binder content increases (Figure 1and).
Figure 1. Dependence of average density (a), compressive strength at 10% deformation (b), bending strength (c) of specimens on the binder content: 1- styrene-butadiene latex; 2- polyvinyl acetate emulsion; 3- sodium liquid glass.

The effect of binder content on compressive strength is shown in Figure 1 b. The optimal binder content for all compositions is in the range of 25-50 (%, wt.), while the compressive strength values are maximum. A further increase in the binder leads to a decrease in the strength index. This is
explained by a decrease in the volumetric content in the material of the reinforcing component - flax waste, which creates the material frame.

Flexural strength of the specimens is higher than the compressive strength and increases with binder content increasing, as it can be seen from figure 1c. This is due to the lamellar shape of flax bonfire particles, which act as a reinforcing element.

A complex binder was used of sodium water glass together with latex for further research. The ratio of organic to inorganic in the complex binder was established (table 2).

**Table 2. Characteristics of samples for various binder compositions.**

| Ratio liquid glass: latex | $\rho_m$ kg/m$^3$ | Rcomp, MPa | Rflexural, MPa | $\lambda$, W / m$^0$C |
|--------------------------|------------------|------------|---------------|-----------------------|
| 0.95/0.05                | 305-310          | 0.58-0.61  | 0.95-1.05     | 0.063-0.065           |
| 0.75/0.25                | 286-290          | 0.66-0.72  | 1.12-1.15     | 0.057-0.059           |
| 0.5/0.5                  | 317-325          | 0.78-0.85  | 1.28-1.35     | 0.075-0.076           |

The data given in the table show that samples, based on an organomineral binder with a component ratio of 0.75 / 0.25, have the lowest average density and thermal conductivity. The samples are characterized by high values of compressive and flexural strength with an equal ratio of inorganic to organic. However, an increase in the content of organic binder leads to an increase in the material cost.

The formation of heat-insulating material structure is influenced by the granulometric composition of the organic filler. Two-way analysis of variance was carried out to determine this effect. The following factors were selected: R - the ratio of flax bonfire to the binder, L - fractional composition of flax bonfire.

During the test, a fire of flax fractions of 2.5 / 1.25 mm, 5 / 2.5 mm, 10/5 mm was used. The use of fraction flax less than 1.25 mm is not advisable in the pressed products manufacture. The factorial experiment RхL type 3х7 was carried out. There are 3 levels for the R factor, and 7 levels for the L factor. The measured characteristics (responses) are average density (Y1) and flexural strength (Y2). The obtained data are shown in Figure 2.

![Figure 2](image_url)

**Figure 2.** Influence of the fractional composition (L) on the average density (a) and bending strength (b) of the costolite samples.

According to the graphs at the L4 and L5 levels, the samples have an average density of 295-300 kg / m$^3$ and a flexural strength of 1.08-1.13 MPa. L4 is ratio of flax bonfire fractions 5 / 2.5: 10/5 = 2: 1, L5 is ratio of flax bonfire fractions 5 / 2.5: 10/5 = 1: 2. The content of the 5 / 2.5 mm fraction in the bulk sample of flax is more than 50%, therefore, the combination of 5 / 2.5 and 10/5 mm flax fractions with a ratio of 2: 1 is optimal.

The hardening mode choice has a significant impact on the finished products’ properties. The samples were hardened in a drying chamber at a temperature of 40-700°C until the samples reached a moisture content of 15%. The upper limit of heat treatment 700°C is set, taking into account the content of the polymer component in the binder. At temperatures below 40 °C, the moisture content of the samples is 15% during the drying time equal to 38 2 hours. The choice of the optimal temperature was
carried out according to the compressive strength set of the specimens. The specimens hardened at 400°C – 500°C have a low strength of 0.25-0.3 MPa, this is due to slow moisture release. The humidity of such samples after 24 hours of heat treatment is 45-55%. There is an intensive release of moisture at 70 °C during the first 4-6 hours, an increase in strength is noted, and further exposure leads to a drop in strength by 5-7%. The optimal temperature range is 60-65°C.

The processes were carried out according to IR spectra study, occurring in the contact zone during the hardening of binders and organic filler. Interaction of flax with a complex binder was established, confirmed by bands in the region of 1743-1492 cm⁻¹ characteristic of lignin rings’ deformation vibrations. The appearance of these bands is associated with the adsorption effect of a complex binder.

A technological scheme for the production of pressed plates, based on flax waste, has been developed. The original flax waste is subjected to fractionation on a flat vibrating sorter. The moisture content of the flax waste is 17-18% at the time of feeding to the dispenser. Flax waste, liquid glass, styrene-butadiene latex, water enters the volumetric dispensers and then into the installation for receiving the kostrolite mass, which is a paddle mortar mixer. Further, the kostrolite mixture is evenly placed in the molds. The height of the mold boarding is 3-3.5 sm, taking into account the coefficient of the mixture compaction. The scaffold mass is compacted with a pressing device and a compaction pressure of 0.03-0.05 MPa. Then it enters drying chamber and it is dried at a temperature of 60-650°C for 6-8 hours. Deforming products are kept at a temperature not lower than 18°C and a relative humidity of indoor air not higher than 80% for 3-5 days and sent to the finished product storehouse. Thermal insulation boards are stored in bags or stacks in conditions that do not allow them to be wet.

3. Conclusions

Pressed materials were obtained on the basis of a complex binder consisting of sodium water glass and styrene-butadiene latex with an organic to inorganic ratio of 1: 2.

The optimal content of the complex binder in relation to the flax waste was found to be 1.15: 1 (parts by weight), depending on the change in the physical and mechanical properties of the pressed samples. The material properties’ dependence on the fractional composition of flax was determined by two-factor analysis method of variance. It was found that the optimal is the use of a polyfraction filler with a fraction ratio of 5 / 2.5: 10/5 mm - 2: 1 (parts by weight).

The optimal composition of the raw mixture for pressed materials has been determined, including, wt%: flax of 5 mm fraction - 23-25; flax waste fraction 10 mm - 13-15; liquid glass - 35-40; styrene butadiene latex - 5-6; water - 17-19.

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