Results of determination of thermal conductivity coefficient for board materials from plant waste

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Abstract. This paper solves the problem of recycling irretrievable waste spinning flax and cotton. This plant waste is incinerated or sent to landfill. It is proposed to use plant waste as a filler for building materials for thermal insulation purposes. New thermal insulating materials based on plant waste are manufactured using the technology of soft fibreboard wet production method. Synthetic thermosetting or inorganic binders are used as the matrix of the composites. The article presents the results of an experimental determination of the coefficient of thermal conductivity of plate materials from irretrievable spinning waste of flax and cotton fibers. Composites based on flax waste filler have a lower value of thermal conductivity coefficient than for cotton waste plates. The results of determining the thermal conductivity coefficient of composite boards based on spinning flax and cotton showed that the developed material can be used as an internal thermal insulating layer of enclosing structures.

1. Introduction

Potential raw material resource for the production of insulating composite materials using plant fillers are irretrievable textile production waste. The renewable raw material base of annuals, the problem of utilization of plant waste, which in the production processes of spinning flax and cotton fibers become irretrievable, all this serves as the basis for developing a new type of product. Practical implementation of the development of these composite materials will allow, along with meeting the needs of construction in low-cost thermal insulation materials, to also solve the environmental problem of cleaning the territories from industrial waste.

Scientists from all over the world are working on the problem of recycling unused plant waste. New composite materials are being developed, consisting of coffee husks [1], wood waste [2-6], tea tree [7,3], coconut husks [8,9], bagassa [10], cotton [11], kenaf [12], flax and hemp fibers [13]. It should be noted that with all the variety of development of composite materials from plant waste, work in the field of insulation materials from irretrievable (unused) waste spinning of flax and cotton in the world and domestic scientific practice is not carried out.

Legislative regulation of work on improving energy efficiency began in our country more than 10 years ago - with the enactment of federal law No. 261 of 11.23.2009 "On energy saving ...". The importance of using efficient insulation, among other factors, is due to the fact that up to 30...49% of heat energy losses through the walls, depending on the height, type of building and its service life [14].

According to many researchers, in the future, energy demand will only increase [15-19], work to improve the efficiency of structures for thermal insulation of buildings and structures will be
increasingly relevant from the point of view of energy saving. Rising prices for thermal energy is also a significant basis for the development of new thermal insulation materials. The creation of effective thermal insulating board materials for construction purposes, including those from local industry wastes, makes it possible to reduce the cost of thermal insulation of buildings.

A good basis for these works are low values of thermal conductivity of plant materials. According to Zhou and colleagues, the thermal conductivity of boards of cotton stalks without a binder has values in the range of 0.0585...0.0815 W/(mK) (depending on the density of the boards 150...450 kg/m³) [20]. Jiří Zach [21] investigated the properties of heat-insulating materials based on hemp, jute and flax. Composite materials developed by the authors have a coefficient of thermal conductivity in the range of 0.041...0.050 W/(mK) depending on the density, type of organic fibers and content of fires. Research on the use of renewable plant resources relevant for the production of effective insulation materials [22,23].

The basis of methods for determining thermal conductivity is the Fourier law. The French mathematician and physicist Jean Baptiste Joseph Fourier and the French physicist and astronomer Jean-Baptiste Biot in 1822 developed the law of isotropic thermal conductivity of the medium. The Fourier law relates the temperature gradient of the environment to the densities of heat flows:

\[ q = -\lambda \frac{dT}{dx}, \]

where \( q \) – is the heat flux, W/m²;
\( \lambda \) – thermal conductivity coefficient W/(mK);
\( \frac{dT}{dx} \) is the temperature gradient on an isothermal flat surface, K/m.

The temperature gradient can be determined by measuring the temperature difference between the hot and cold surfaces of the plates:

\[ \Delta T = T_{\text{hot}} - T_{\text{cold}}, \]

where \( T_{\text{hot}} \) is the temperature of the hot surface of the plate, K;
\( T_{\text{cold}} \) – the temperature of the cold surface of the plate, K.

The average temperature gradient is defined as

\[ \frac{dT}{dx} = \frac{-\Delta T}{\Delta x}, \]

where \( \Delta T \) is the difference between the temperature of the hot and cold surfaces of the plates, K;
\( \Delta x \) – sample thickness, m.

To determine the thermophysical properties of materials using non-stationary and stationary methods. The essence of the stationary method lies in the fact that through the sample a constant heat flux is formed over time, that is, the thermophysical parameters of the material do not change with time. This allows you to determine the thermal resistance of the material and its effective thermal conductivity.

2. Methods

In this work, the heat-engineering properties of composites from irretrievable spinning of flax and cotton based on a matrix of synthetic and inorganic binders are investigated. Composites were manufactured using wet fiberboard technology. The plant filler was mixed with water and a binder, briquettes were molded, pressed in a device in a cold press, then the samples were dried at a temperature of 100 °C. Phenol-formaldehyde (PF) resin, urea-formaldehyde (UF), liquid glass Na₂O(SiO₂)_n and aluminum chromophosphate CrAl₃(H₂PO₄)_n were used as binders.

Research of the thermal conductivity coefficient of composite materials based on plant waste was carried out using an ITP – MG – 4 thermal conductivity meter in accordance with GOST 7076–99 “Building materials and products. Method for determination of thermal conductivity and thermal
resistance in a stationary thermal regime”. The essence of the test method is to create a heat flux directed perpendicular to the largest side of the sample of a certain thickness, measuring the density of the stationary heat flux and temperatures on the opposite sides of the sample. The appearance of the electronic meter of thermal conductivity ITP–MG–4 is shown in fig. 1.

![Electronic meter of thermal conductivity ITP – MG – 4.](image)

### 3. Results

The coefficient of thermal conductivity was determined on samples with dimensions of 100×100×h mm, the height of samples h was 20...30 mm. For each composite, the tests were carried out on five samples. Before testing, the samples were kept in the laboratory for 24 hours. The temperature of the laboratory room was 20±1 °C. The specimen was placed in the installation for heating, the height of the specimen was entered on the keyboard of the electronic unit. The duration of heating the sample in the installation was 80...120 minutes.

According to the results of the experimental determination of the coefficient of thermal conductivity for different batches of composites made from fillers - waste of flax and cotton and synthetic and inorganic binders, statistical indicators were determined. Average values thermal conductivity coefficient λ, W/(mK) are presented in table 1.

### 4. Conclusions

The work experimentally determined the coefficient of thermal conductivity of composite materials from irretrievable waste spinning flax and cotton, produced by the technology of soft fibreboard. For all types of composites, thermal conductivity values reflect the ability to effectively inhibit the passage of heat through the board material. Composites based on flax waste, both on the basis of thermosetting binders — PF and UF, and inorganic — liquid glass and aluminum chromophosphate — have a greater thermal resistance value and lower thermal conductivity compared to cotton waste boards.

The difference in the effective thermal conductivity of materials based on filler from the lot moves flax and cotton is explained by the different structure of the plant cells of the filler. Flax elementary fiber differs from cotton fiber in structure and size [24]. Flax elementary fibers have an average length of 10...24 mm, even if the fibers in the waste are damaged, one end of the fiber is closed, that is, the inner cavity of the elementary fiber is a semi-closed pore. Cotton fiber has an open cavity along the entire length. This provides a lower thermal conductivity of composites of flax in comparison with the material based on cotton waste.
Table 1. The results of determining the coefficient of thermal conductivity.

| Binder consumption, in % by weight filler | Heat conductivity coefficient, W/(mK) | (above the line for cotton boards, below the line for flax boards) of boards on the binder |
|------------------------------------------|--------------------------------------|-------------------------------------------------------------------------------------|
|                                          | Phenol-formaldehyde                  | Liquid glass Na$_2$O(SiO$_2$)$_n$                                                | Aluminum chromophosphate CrAl$_3$(H$_2$PO$_4$)$_n$ | Urea-formaldehyde |
| 0                                        | 0.081                                | 0.081                                                                                | 0.081                                                | 0.081              |
| 2                                        | 0.084                                | 0.084                                                                                | 0.084                                                | 0.084              |
| 4                                        | 0.084                                | 0.084                                                                                | 0.084                                                | 0.084              |
| 8                                        | 0.085                                | 0.085                                                                                | 0.085                                                | 0.085              |
| 12                                       | 0.086                                | 0.086                                                                                | 0.086                                                | 0.086              |
| 16                                       | 0.087                                | 0.087                                                                                | 0.087                                                | 0.087              |
| 20                                       | 0.088                                | 0.088                                                                                | 0.088                                                | 0.088              |
| 24                                       | 0.089                                | 0.089                                                                                | 0.089                                                | 0.089              |
| 30                                       | 0.090                                | 0.090                                                                                | 0.090                                                | 0.090              |

Materials with a thermal conductivity of 0.035...0.16 W/(mK) are thermally insulating [25]. The values of thermal conductivity of conventionally used materials:
- mineral wool 0.033 ... 0.055 W/(mK);
- hardwood 0.16 W/(mK);
- softwood 0.12 W/(mK);
- fibreboard 0.04 ... 0.06 W/(mK).

Thus, the study showed that the developed composite materials from irretrievable waste spinning of flax and cotton fibers can be used as a thermal insulating element for the enclosing structures of buildings and structures.

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