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Justification of the Wood Polymer Material Application Conditions

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Abstract. The production of heat-insulating materials based on wood was analyzed in this paper. The expediency and efficiency of using wood waste were established. A study of the operational properties of the sample obtained from wood shavings polymerized with mixtures of polyester and epoxy resins was carried out. It was proven that the process's primary regulator is the material's density and porosity. Also, an increase in humidity and wetting reduces heat-insulating indicators. Based on thermophysical dependences, the thermal insulation properties of the samples were calculated. Moreover, it was established that the thermal conductivity does not exceed $0.21 \cdot 10^{-6}$ m²/s, and the thermal conductivity of the sample – $2.85 \cdot 10^{-3}$ W/(m·K). Therefore, these products can be classified as heat-insulating materials. A through-thickness compressive strength study showed that the wood shavings and polyester resin material are more fragile, and the strength limit was reduced by more than 1.2 times compared to the epoxy resin-based material. The moisture absorption results showed that a heat-insulating product made of shavings polymerized with polyester resin. Moisture absorption was 5 % after 90 days of exposure to water. On the other hand, the heat-insulating products made of shavings with epoxy resin of 4.41 % showed their resistance to moisture absorption.

Keywords: wood shavings, dry glue, tensile strength, moisture absorption, heat insulation.

1 Introduction

Ease of processing, low weight with relatively high strength, and heat-insulating properties of wood contribute to a wide range of applications in construction. Today, the field of application of wood is vast, but its use has become frugal. Gluing waste generated during wood processing (shavings, lumpy waste with knots and cracks) with synthetic resins and glues allows obtaining glued wooden products of significant sizes, chipboards and fiberboards, and heat-insulation products.

The use of dry adhesive mixtures during the formation of heat-insulating products from wood chips increases the products' environmental safety and weather resistance since such resins are characterized by resistance to water and temperature changes. All this leads to a decrease in the thickness of the enclosing structures, a decrease in the mass of buildings, the consumption of building materials, and a decrease in the share of energy carriers for heating. The main technical characteristic of the obtained heat-insulating materials is thermal conductivity, that is, the ability of the material to transfer heat, which depends on the density of the material, its type, size, and location of cells with air. Besides important properties of heat-insulation materials are compressive strength, moisture absorption, sorption moisture, vapor permeability, frost resistance, and fire resistance. In this regard, there is a need to determine the thermophysical properties of wood shavings products and dry mixtures of polyester and epoxy resins, which led to research in this direction.

2 Literature Review

The research [1] aims to preserve the environment and reduce the use of non-renewable raw materials as much as possible. After all, the construction sector can contribute to preserving the environment by using biomaterials. Bio-building materials consist, at least in part, of components made from biomass derived from plants or animals. Today, these materials are used in various products and for various purposes, including insulation, mortar and concrete, panels, plastic composites, and construction chemicals. At the first stage of this study, the physicochemical (bulk density, absolute density, water absorption, relative humidity) and thermal (thermal conductivity and specific thermal resistance) properties of wood and plant aggregates (sunflower bark and core) were studied and compared with the results of a literature review. After that, different mixtures were prepared with a certain percentage of cement used as a binding material (0, 10, and 20 %) to improve their mechanical properties. Then, concrete was prepared from wood and vegetable fillers (sunflower bark or core) to optimize the mixture, which has the best thermal and mechanical properties. The compressive and bending strength increase was evaluated at 7, 14, 28, and 90 days. Due to the excellent ability of wood to maintain cohesion, the obtained results demonstrated the possibility of producing a mortar with less cement. In terms of thermal characteristics, an increase in fiber content with a simultaneous decrease in bulk density can reduce the thermal conductivity of mortars.

Work [2] shows research that focused on the production of insulating panels using fungal mycelium and lignocellulosic materials as substrates. The process was optimized, starting with the selection of isolates of Trametes versicolor, Pleurotus ostreatus, P. eryngii, Ganoderma carnosum, and Fomitopsis pinicola, followed by the evaluation of three-grain substrates (millet, wheat and a 1:1 mixture of millet and wheat) for mycelial propagation and ending with the production of various of mycelium-based composites using five by-products and wood waste (pine, oak shavings, wood shavings, wheat straw and chopped beech wood). The obtained biomaterials were characterized by their internal structure using X-ray micro-CT, thermal permeability using a thermoflowmeter, and moisture absorption. The results showed that using a 1:1 mixture of wheat and millet is the best option for production regardless of the fungal isolate. In addition, the final composites' performance was influenced by the fungal isolate and the substrate used.

Moreover, the latter had a more decisive influence on the measured properties. The study shows that the most promising sustainable insulating biomaterial was created using T. versicolor grown on wheat straw. This is not indicated regarding the scope of application of such products.

In article [3], the heat and sound insulation properties of inexpensive wood-plastic composites (WPC) made from Acacia saligna biomass waste and recycled low-density polyethylene (LDPE) were studied. WPC was produced in three different mixing ratios (50, 60, and 70 % wood), with two particle sizes (0.3 and 0.5 mm), at different hot pressing times (10 and 30 min) and temperatures (150 and 180 °C) to obtain boards with optimal mechanical, physical, thermal and sound insulation properties for social housing applications in South Africa. To measure the thermal conductivity (k-factor) and sound transmission loss (STL) of the WPC, a heat flux meter (HFM) and an acoustic impedance tube were designed and manufactured. Boards with larger particles had lower values of electrical conductivity. Boards with a biomass content of 70 % and at a lower temperature and time of pressing had the lowest thermal conductivity of 0.044 W/(m·K). The higher frequency of lattice defects can explain this due to the higher proportion of thermally modified biomass. Boards pressed with 50 % biomass content at 150 °C for 10 min had a higher mass/stiffness ratio, resulting in improved STL due to reflection and absorption of acoustic energy at medium frequencies 500–2000 Hz. Boards made from 60 % biomass showed the best level of noise reduction of 8–14 dB and thermal conductivity of 0.048–0.056 W/(m·K), making them the most suitable insulation materials. However, the effect of water is not defined.

The research [4] is devoted to solving the problem related to one of the methods of processing plastic waste by adding various fillers to obtain the final product for producing heat-insulating materials. Samples of unsaturated polyester resin (UPR) from expanded polystyrene (EPS) plastic waste and shredded recycled polyethylene from greenhouse film waste with various carpentry wood waste were used. Tests have shown that when wood waste is added to unsaturated polyester mixtures, the coefficient of thermal conductivity of the material decreases with a slight lowering in density. This provides ample opportunities to use carpentry workshop waste as an additive to UPR and expands its potential industrial use. The addition of styrene in compositions containing 10 % polystyrene causes an apparent decrease in heat-conducting characteristics and a slight decrease in the density of these mixtures. The thermal conductivity values and density of low, consistent polyethylene material increase with the accreting percentage of wood powder used as organic filler. However, this composite does not mention the maximum percentage of wood.

The article [5] presents the results of the study of thermal and gyroscopic characteristics of three new insulation prototypes developed from biomaterials or waste materials. Experimental development and characterization of insulation using corn cob, recycled bedding (polyester blanket), and prototype wheat straw insulation are presented. Hygroscopic and thermal indexes are compared with an insulating product made of mineral wool. As part of this work, a series of large-scale thermal conductivity and moisture absorption studies were also carried out, examining the performance of each timber frame wall insulation product under steady state and variable environmental conditions. This work was part of a larger international research project aimed at developing insulation materials from biological materials and waste and will contribute to the development of the market for new materials and products for basic construction.

The use of lignocellulosic fillers in rigid polyurethane foams (RPUF) has attracted much attention due to their high mechanical and insulating properties and the significant environmental appeal of the resulting porous polymers. Although high water absorption is observed in most of these systems [6]. To mitigate this deleterious effect, RPUFs (with 2.5 % wood flour) were manufactured with the addition of furfuryl alcohol (FA) to create a polymer grafted with wood filler (10 and 15 %). Cell morphology, density, compressive properties, thermal stability, and water absorption characterize these materials. The introduction of wood flour as a filler reduced the cell size and increased the anisotropy index of RPUFs. In addition, FA inoculation further enhanced these effects. In general, no significant changes in mechanical and thermal properties were associated with introducing fillers. On the other hand, FA-treated fillers were attributed to a significant reduction in water absorption. However, the scope of application of this product is not specified.

In [7], a multifunctional biomass aerogel using wood waste as a raw material is proposed. The composite airgel consists of curdlan as a structural framework, wood fibers, and nanohydroxyapatite as reinforcing phases. Thermogravimetry (TG), infrared thermal imager, and thermal conductivity meter were used to evaluate the thermal stability and thermal insulation characteristics of the airgel. Accordingly, thermal conductivity reaches 0.003 W/(m·K). As the strength and viscosity of the aerogel are improved by introducing cellulose into the matrix, it exhibits a maximum compressive modulus of 1.65 MPa. The alkylation method achieves the hydrophobicity of the aerogel, and the contact angle is more than 120°. This non-toxic aerogel composite with high thermal and mechanical properties has potential use as a thermoregulation material in the food and electronics industries.

The research presented in [8] concerns the development of sustainable materials and processing of natural waste, namely wood and hemp by-products. Cellulosic nanomaterials derived from these underutilized wastes and by-products also serve as promising natural precursors for advanced applications such as biomedical, pollution filtration, and thermal insulation. Wood and hemp fibrils were obtained by microfluidic treatment of aqueous cellulose suspensions of 0.2–1.0 %. After freeze-drying, the obtained foamed materials have a bulk density of 2–36 kg/m^3. The key characteristics of the obtained hemp and wood nano-cellulose (NC) foams were investigated by the mechanical response, porosity, BET analysis, thermal conductivity, thermal degradation, chemical composition, and morphology. Hemp NC foams showed superior performance, coinciding with nearly doubled fibril length, 1.5 times higher cellulose content, and a more uniform mesh structure than wood NC foams. In addition, the thermal indicators of the obtained NC foams were in the range of 34–44 mW/(m·K), contributing to their more comprehensive application.

Heat gain reduction, thermal peak displacement, and air temperature fluctuation mitigation are desirable properties for any thermal insulation system [9]. It cannot be overstated that these factors, in addition to others, determine the performance of such systems and their impact on indoor environmental conditions.

The effect of such systems also extends to heating, ventilation, and air conditioning (HVAC) systems, which are configured to perform optimally in certain conditions. From the analysis of previous studies, it has been found that plastic polymer materials (PPM) and natural materials such as wood shavings can provide effective passive insulation for buildings. Such approaches require the use of complex methods, for example, microencapsulation. Considering technical and economic aspects, a mixture of PCM and wood shavings was created for thermal insulation. Amalgamation was performed using the most straightforward methods by immersing wood shavings in PPM. An experimental procedure was developed to test the thermal performance of amalgam and compare it with the characteristics of non-amalgamated materials. A comparative analysis showed that no significant thermal benefits are expected from such a combination.

Nevertheless, a significant reduction in the total weight of the insulation system of up to 21% will be achieved. Thus, possible loads on structural elements due to the use of insulation on buildings are further reduced. This can be particularly useful in vernacular architectural approaches where significantly more significant amounts and thicknesses of insulation are used. In addition, cost reductions can be achieved as wood chips are significantly cheaper than PPMs.

In order to obtain light wooden building materials with good thermal insulation, energy-saving properties, and satisfactory mechanical properties, polyvinyl chloride pipes from low-density fiberboard and hollow wood composites (HWC) were produced by the hot pressing method [10]. Polyethylene glycol was used as a phase transition material to fill polyvinyl chloride tubes and obtain a phase change hollow wood composite (PHWC). The physico-mechanical properties of HWC and PHWC were tested, and their thermal properties were analyzed and modeled. The results showed that the thermal conductivity of low-density fiberboard, HWC, and PHWC ranges from 0.06 to 0.07 W/(m·K). This indicates they have sufficient physical and mechanical properties for heat-insulating building materials. The combination of series and parallel models accurately predicted the thermal conductivities of HWC and PHWC, whose structures were similar to the series structure. Adding polyethylene glycol to the HWC allowed the PHWC to retain latent heat and reduce indoor temperature fluctuations. Heat transfer modeling showed that when used as a non-structural building wall material, the PHWC wall had better energy efficiency than the concrete wall. Thus, PHWC has potential thermal insulation and phase-change building mate applications.

Thus, the production of heat-insulating products from wood waste and dry mixtures of polyester and epoxy resins for construction requires the determination of thermophysical properties necessary for the design and manufacture of heat-insulating products, as well as the determination of compressive strength and moisture absorption, which is the purpose of this work.

3 Research Methodology

The work aims to establish the thermophysical characteristics, compressive strength, and moisture absorption of the product made of wood shavings and dry mixtures of polyester and epoxy resins to determine the conditions of use in building construction. To achieve this goal, the following tasks were set:

– to establish thermophysical characteristics for a thermal insulation product made of wood shavings and dry mixtures of polyester and epoxy resins;

– to investigate the thermal insulation product's compressive strength and moisture absorption.

To study the thermal conductivity of the heat-insulating product from the wood polymer mixture, samples were made by mixing shavings and dry mixtures of resins in a ratio of 1:2, from which a carpet with dimensions of about 150×150×20 mm was formed, and thermal sintering was carried out at a temperature of 200 °C for 20 minutes (Figure 1).

Figure 1 – A sample of research material

Special equipment was used to study the heat-insulating properties of materials [11].

In order to establish the operational properties of the thermal insulation product, absorption and technological properties were determined, particularly the ability to absorb moisture and compressive strength. Determination of the water absorption amount by samples of wood polymer materials was carried out according to the working method. The essence was the experimental determination of the amount of moisture absorbed by the sample during its exposure to a desiccator [12]. Determination of the compressive strength of the manufactured materials was carried out according to ISO 13061-3:2014 "Physical and mechanical properties of wood – Test methods for small clear wood specimens – Part 3: Determination of ultimate strength in static bending".

In order to establish the thermophysical characteristics of the materials, namely the heat-insulating product made of wood shavings, studies were conducted on their thermal conductivity under the action of the heating device (Figure 2).

Figure 3 presents a stand for studying the resistance of wood polymer material to compression. Figure 4 presents the stand for studying the moisture absorption of a sample of wood shavings and dry adhesive mixtures.

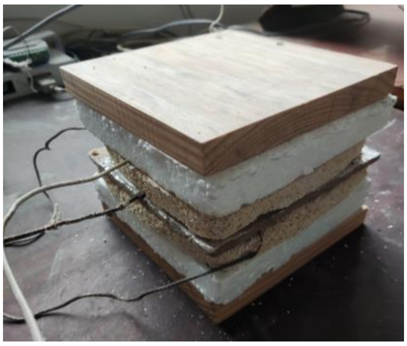

Figure 2 – Determination of the thermal conductivity of the thermal insulation product made of wood shavings under the action of the heater

Figure 3 – Determining the compressive strength of wood chips and dry mixes

Figure 4 – The process of determining the degree of moisture absorption of a product made of shavings and dry adhesive mixtures

4 Results

The results of research on determining the temperature and duration of the induction time of heat transfer through a sample made based on wood shavings and dry mixtures of polyester and epoxy resins are shown in Figure 5.

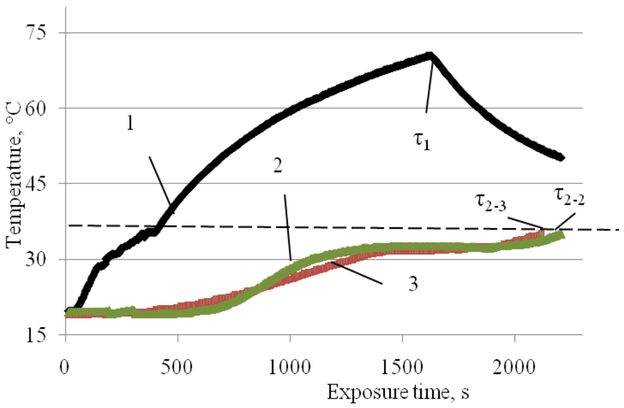

Figure 5 – The results of thermal conductivity tests of the thermal insulation product: 1 – heating curve, 2 – temperature value on the inverted surface for the product based on shavings and polyester resin, 3 – temperature value on the inverted surface for the product based on sawdust and epoxy resin

The curve τ_1 corresponds to the heating curve's temperature value, τ_2 – to the temperature value on the inverted surface.

Based on the results of the measured temperature according to the method given above, the thermophysical characteristics of materials based on wood shavings and resin were calculated (Table 1).

Thus, it was established that the thermal insulation product's thermal conductivity was no more than $0.21\cdot10^{-6}$ m^2/s. The sample's thermal conductivity did not exceed $2.85\cdot10^{-3}$ W/(m·K). In addition, the heat capacity of the product corresponds to a value in the range of 70–90 kJ/(kg·K), which is accordingly classified as a heat-insulating material.

Tables 2–3 show the results of studies of the resistance of wood polymer material to compression.

Table 1 – Thermophysical characteristics of a heat-insulating product made of wood shavings

Material	Thickness, mm	Weight, g	Density ρ, kg/m^3	Thermal activity W,· s$^{1/2}$/(m^2·K)	Thermal conductivity 10^{-6} m^2/s	Thermal conductivity λ, 10^{-3} W/(m·K)	Heat capacity, kJ/(kg·K)
Mixture with polyester resin	19.2	177	415	6.22	0.20	2.80	33.22
Mixture with epoxy resin	19.0	175	384	6.22	0.21	2.85	32.15

Table 2 – Strength limit of material samples from shavings for compression in thickness

Sample	Dimensions, mm		Force P_{max}, N	Strength limit σ, MPa	Deformation, mm
	b	h			
The material is a mixture of wood shavings and epoxy resin					
1.1	22.00	25.20	1263.87	2.3	11.60
1.2	25.15	25.30	2035.28	3.2	12.20
1.3	25.65	23.40	1184.40	2.0	11.70
1.4	25.60	25.00	1560.90	2.4	11.50
1.5	24.15	26.10	1326.90	2.1	11.70
Average value	24.51	25.00	1474.27	2.4	11.74
The material is a mixture of wood shavings and polyester resin					
2.1	25.60	26.85	996.25	1.4	12.50
2.2	24.25	24.35	1189.49	2.0	11.20
2.3	25.75	24.35	1009.09	1.6	12.60
2.4	26.45	28.70	1713.73	2.3	11.10
2.5	27.85	26.20	1814.57	2.5	13.90
Average value	25.98	26.09	1344.63	1.96	12.26

Table 3 – Strength limit of material samples from shavings when crushed on an edge

Sample	Dimensions, mm		Force P_{max}, N	Strength limit σ, MPa	Deformation, mm
	b	h			
The material is a mixture of wood shavings and epoxy resin					
1.1	25.10	19.80	325.00	0.7	4.60
1.2	25.45	17.60	215.62	0.5	3.30
1.3	25.60	17.90	188.35	0.4	5.20
1.4	25.20	19.35	282.51	0.6	2.20
1.5	25.55	25.55	150.00	0.2	2.50
Average value	25.38	20.04	232.30	0.47	3.56
The material is a mixture of wood shavings and polyester resin					
2.1	28.00	19.70	201.76	0.4	2.70
2.2	24.45	18.15	309.41	0.7	2.40
2.3	25.75	17.45	140.00	0.3	4.20
2.4	24.50	18.80	250.44	0.5	1.80
2.5	26.00	20.90	370.35	0.7	2.80
Average value	25.74	19.00	254.39	0.52	2.78

Through-thickness compressive strength studies have shown that the material based on wood shavings and polyester resin is more fragile, so the strength limit is more than 1.2 times lower than the material containing epoxy resin. A study to determine the compressive strength when crushing on a rib showed almost the same values: 0.47 MPa for the epoxy-based product and 0.52 MPa for the polyester resin. Accordingly, the compression deformation along the compression thickness for a product based on polyester resin exceeds the value for epoxy resin.

Table 4 shows the moisture absorption results of a sample of wood shavings and dry adhesive mixtures after exposure to water for 30 and 90 days.

The analysis of the results of experiments on the moisture absorption of material samples from wood shavings and dry glued mixtures shows that the maximum increase in mass under the action of water on samples in the composition of epoxy resin was 4.41 %, and based on polyester resin – 5 % after 90 days of exposure to water.

Simultaneously, the volumetric moisture absorption β of wood shavings and epoxy resin material is 1.06 times less than that of the product based on polyester resin.

Table 4 – Moisture absorption of samples from shavings and dry adhesive mixtures after exposure in water

Initial weight m_0, g	Initial dimensions, mm			Weight after exposure in water, mm		Weight moisture absorption W, %	Dimensions after exposure in water, mm			Volumetric moisture absorption β, %
	b_0	h_0	l_0	30 days	90 days		b	h	l	
The material is a mixture of wood shavings and epoxy resin										
5.16	25.17	25.13	19.21	5.35	5.39	4.41	25.57	25.58	19.70	6.01
The material is a mixture of wood shavings and polyester resin										
5.18	25.15	25.56	18.86	5.39	5.44	5.00	25.53	26.02	19.40	6.32

5 Discussion

The thermal conductivity of the wood product depends on the density or volumetric mass. Thus, with a decrease in the density of the material, thermal conductivity deteriorates, and vice versa. When it increases, it improves. In addition, heat-insulating building materials and wood products must meet specific requirements. That is, to have stable thermal insulation performance during the entire period of operation, high compressive strength, resistance to water absorption, vapor permeability, frost resistance, and to be fire resistant and not release harmful substances into the environment. This agrees with the data given in works [13, 14], the authors of which also link the effectiveness of creating heat-insulating materials from wood and their fire protection.

In contrast to the research of the authors cited in [15], the obtained data on the influence of the structure on the process of heat transfer and changes in insulating properties allow us to state the following:

– the primary regulator of the thermal insulation process is the density and porosity of the material since high density and low porosity lead to temperature equalization;

– a significant influence on the process of thermal insulation when using wood is carried out in the direction of the orientation of its parts.

The results of detecting the thermal insulation process of wood shavings polymerized with dry mixtures of adhesive substances indicate their ambiguous influence on the change in the effectiveness of the binder. Such uncertainty cannot be resolved within the framework of the above study because it would be necessary to conduct additional experiments to obtain more reliable data.

However, the obtained data are sufficient for qualitatively carrying out the heat insulation process and identifying the moment when the drop in heat resistance begins. Such detection will allow for determining those variable conditions that significantly affect the beginning of the transformation of this process.

6 Conclusions

The thermal conductivity of the heat-insulating material was no more than $0.21 \cdot 10^{-6}$ m^2/s, and the sample's thermal conductivity did not exceed the value of $2.85 \cdot 10^{-3}$ W/(m·K).

In addition, the heat capacity of the product corresponds to a value in the range of 70–90 kJ/(kg·K), which is accordingly classified as a heat-insulating material.

Through-thickness compressive strength study showed that the wood shavings and polyester resin material are more fragile, so the strength limit is reduced by more than 1.2 times compared to the epoxy resin-based material. A study to determine the compressive strength when crushing on a rib showed almost the same values: 0.47 MPa for the product based on epoxy resin and 0.52 MPa based on polyester resin. Accordingly, the compression deformation along the compression thickness for a product based on polyester resin exceeds the value for epoxy resin.

Features of determining the process of moisture absorption showed that for a heat-insulating product made of shavings polymerized with polyester resin, moisture absorption is 5 % after 90 days of exposure to water. On the other hand, the value of heat-insulating products made of shavings with epoxy resin is 4.41 %, which shows their resistance to moisture absorption.

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