ДЕРЕВООБРАБАТЫВАЮЩАЯ ПРОМЫШЛЕННОСТЬ

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THERMAL INSULATION PANELS FROM TREE BARK

To reduce the energy consumption of buildings, natural-based insulation materials are being investigated today. The annual million tones amount of bark waste allows it to be used as an alternative material with the least impact on the environment. Various additives are being investigated to improve the physical and mechanical properties of bark insulation panels. In this study, the mechanical, physical, thermal properties of 11 types of composite insulating panels from the bark of the Pannónia poplar (*Populus* × *euramericana* cv. *Pannónia*) were manufactured and investigated. The bark panels were supplemented and reinforced by short glass fibers, overlaying fibreglass mesh, fibreglass mat and fibreglass woven fabric and two types of paper, as well as an inner glass fiber mesh. The target density of the panels was 350 kg/m³, and the thermal conductivity of the panels varied from 0.067 to 0.078 W/mK. Although the thermal conductivity of artificial insulation materials is lower, panels made of natural materials have less impact on the environment. Glass fiber reinforcement had little effect on thermal conductivity and mechanical properties. The preliminary heat treatment of the raw material influenced the thermal conductivity due to changing the structure and the appearance of cavities. It had an effect on the density that determines thermal conductivity.

Key words: tree bark, thermal insulation, reinforcement, glass fiber.

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ТЕПЛОИЗОЛЯЦИОННЫЕ ПАНЕЛИ ИЗ ДРЕВЕСНОЙ КОРЫ

Чтобы снизить энергопотребление зданий, сегодня исследуются изоляционные материалы на натуральной основе. Ежегодное количество отходов коры в миллионы тонн позволяет использовать его в качестве альтернативного материала с наименьшим воздействием на окружающую среду. Изучаются различные добавки для улучшения физико-механических свойств изоляционных панелей из коры. В этом исследовании были изготовлены и исследованы механические, физические и термические свойства 11 типов композитных изоляционных панелей из коры тополя Паннония (*Populus* × *euramericana* cv. *Pannónia*). Панели из коры были дополнены и усилены короткими стекловолокнами, наложенными на них сеткой, матом и тканью из стекловолокна, двумя типами бумаги, а также внутренней сеткой из стекловолокна. Целевая плотность панелей составляла 350 кг/м³, а теплопроводность панелей варьировалась от 0,067 до 0,078 Вт/мК. Хотя теплопроводность искусственных изоляционных материалов ниже, панели из натуральных материалов оказывают меньшее воздействие на окружающую среду. Армирование стекловолокном оказало небольшое воздействие на теплопроводность и механические свойства. Предварительная термообработка сырья повлияла на плотность материала, определяющую теплопроводность.

Ключевые слова: кора дерева, теплоизоляция, армирование, стекловолокно.

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Introduction. As most researchers have accepted climate change, reducing energy consumption has become more important. Buildings in total, are reported to consume 40% of the EU's total energy demand and produce about 35% of greenhouse emissions. The improvement of energy efficiency on the existing and new buildings could be achieved by enhancing the thermal performance of building envelopes such as walls, roofs and floors [1]. As the environmental aspects come into the fore, the importance of natural-based, recyclable materials and solutions is increasing, and therefore the research of natural-based insulation materials is continuous.

Several studies have investigated insulation of natural materials made from cotton stalk fibers [2] to wheat straw [3]. Insulation made of plant particles or fibers have 0.037–0.065 $W \cdot m^1 \cdot K^1$ thermal conductivity [4]. Bark was also among the investigated materials [5]. Each year million tons of bark are generated during wood processing globally [6]. According to several studies, bark panels have worse physical and mechanical properties than wood panels, but they can be improved [7]. In panels made of mixed wood-bark, increasing the bark content deteriorated the physical and mechanical properties of the panel [8]. Bark with long fibers is more suitable for manufacturing panels [9]. It is important to note that the increase in bark content caused a decrease in the formaldehyde released by the panels [10].

The resulting weakness of the mechanical properties of the manufactured bark-based panels can be improved by reinforcement of bark particle boards with common synthetic polymer fibres such as glass, carbon, basalt and aramid fibres. Research on iberglass reinforced wood products started in the 1960s, with wood-fibreglass composite beams by Wangaard (1964) and Biblis (1965). Since then, iberglass has been used by many researchers as external bonding, internal bonding, or near surface bonding reinforcement to increase the flexural stiffness and strength of wood composites, including MDF boards [11], plywood [12], laminated strand lumber [13], laminated veneer lumber [14] and glulam timbers. Glass fibres have been examined as inside reinforcing filaments in cement and concrete composites [15] and wood-plastic composites [16].

The thermal conductivity of wood and wood products is influenced by many factors: density, moisture content, chemical composition, porosity, grain direction, etc. [17]. Heat treatment of wood improves the dimensional stability of wood by reducing equilibrium moisture content, water uptake, and thickness swelling; while some strength properties decrease [18]. Thermal conductivity also decreases after thermal treatment [19].

Abbreviations

TS	thickness swelling (%)
WA	water uptake (wt %)
EMC	equilibrium moisture content (%)
ρ	density (kg/m^3)
λ	thermal conductivity (W/m·K)
MOE	modulus of elasticity (MPa)
MOR	modulus of rupture (MPa)
IB	internal bond (MPa)

Main part. Materials.

1. The raw material was bark slabs of Pannónia poplar (*Populus × euramericana* cv. *Pannónia*) without separation of the inner and outer bark, peeled off from poplar trees at a local sawmill, in Sopron, Hungary. The bark parts were reduced in size and chopped into particles using a hammer mill equipped with 8-mm screening holes. Afterwards, the bark particles were fractionated (3 PRO Fritsch Analysette) with different sieves, bark particles ranging from 0.5 mm to 8 mm were collected to manufacture bark-based panels and dried until a final moisture content of 6–9% was reached.

2. For heat pre-treatment the raw material was heated to 180°C. According to the heating schedule, the bark chips were heated from room temperature to 95°C in 1 hour, from 95°C to 130°C in another 2 hours, the 180°C top temperature was achieved after half an hour. Three different treatment durations (keeping temperature) were used which lasted 1 (T1), 2 (T2) and 3 (T3) hours. When cooling, the thermal inertia of the chamber was take advantage of, so the specimens were cooled to 25°C in about 15 hours.

3. For surface reinforcement, three main commercial forms of iberglass, i.e. iberglass mesh (GFRP1), iberglass mat (GFRP2) and iberglass woven fabric (GFRP3) were used as surface layers in the analysis of the proposed panels. Two types of paper sheets, one thicker double layer recycled paper (P1) and a thinner thermomechanical pulp (TMP) coated paper (P2) also were used as reinforcement, and were bonded with urea-formaldehyde resin and pressed on both sides of the bark-based insulation panels. Their main properties, grammage (g) and tensile index (TI), were tested according to TAPPI T 410 (1998) and TAPPI T 494 (1996) standards, respectively.

The wetting behaviour of the surfaces of the paper sheets was characterized according to TAPPI T458 (2004) using a 68-76 PocketGoniometer PGX+ model. Static measurements of contact angles (CA) and immersional wetting calculations (ΔG_i) were carried out with distilled water and DIM (3.3′-Diindolylmethane) (Table 1).

4. For under surface reinforcement, two fiberglass mesh sheets with different grid sizes (M1 and M2, respectively) suitable as reinforcement materials were supplied by Tolnatext Bt. (Tolna, Hungary). Their main characteristics are given in Table 2.

Table 1

Sheet thicknesses and main properties of the paper sheets used in the research, according to TAPPI standards

Types of paper sheets	Sheet thickness, μm	Sheet grammage, g/m^2	MD[1] tensile index, Nm/g	CD[2] Tensile index, Nm/g	CA,		ΔG, mJ·m^{-2}	
					Upper	Glued	Upper	Glued
P1	278	194	60.19	22.28	109.8	71.4	24.66	23.22
P2	116	88.6	53.62	30.32	96.5	113.9	8.24	29.49

[1]MD – machine direction.
[2]CD – cross direction.

Table 3

Main properties of glass fibres

Product Code	Type of fibres	Filament diameter, microns	Linear density, Tex	MC, %	Breaking strength, gf/tex
EC 14-300-350	E-glass Silane modified	14.0 ± 1.5	300 ± 15	<0.20	>45

5. The E-glass fibre roving used for this study was supplied by PD Tatneft-Alabuga Fiberglass LLC (Yelabuga, Russia).We manually cut lengths of 12 mm (GF_12), 18 mm (GF_18), 24 mm (GF_24) and 30 mm (GF_30) from the fibreglass roving cylindrical packages. The main properties of the glass fibres used in this work are given in Table 3.

Table 2

Basic properties of fiberglass meshes used in this work

Properties		(M1)	(M2)
Weight, g		75	53
Grid size, mm		3.0×2.5	4.4×4.2
Tensile strength, N/5 cm	Warp	350	850
	Weft	760	1000

6. The commercial UF resin and hardener used in this work was purchased from DUKOL Ostrava s.r.o. (Kronores CB 1104 D).

Panel production. The different panel version is prescribed under the paragraph below signed be letters in brackets.

1. A 4% urea-formaldehyde resin was used for the production of core-layered, bark-based panels. An aqueous solution (35%) of ammonium sulfate used as a hardener (3% solid content) was added to catalyze the resin curing. The bark particles were mixed with the resin system in a laboratory blender for 5 min to ensure a homogeneous mixture. Thereafter, the resin/bark particles mixture was formed into a wood frame mould; the mixture was manually pre-compacted and then the frame was removed.

Bark based insulation panels 500×500 mm, a nominal thickness of 20 mm and a target density of 350 kg/m^3 were produced using a laboratory hot press (Siempelkamp). The pressing time was 18 seconds per final thickness in millimeter, and the temperature of the plates were 180°C. The pressure of the plates initially was 2.86 MPa which was reduced after 120 seconds to 2 MPa, and after 240 seconds to 1.15 MPa to reduce the vapor pressure. Without these steps the vapor could damage the panel.

2. Each fiberglass type mat was overlaid on the top and bottom faces of the bark-based panels after hot pressing. The assembled GFRP structures were then bonded onto core layers using a 2K epoxy resin (Elan-tech EC 152; W152 HR) to form the panel. The epoxy-based adhesive was brushed onto the surface of bark panel and also onto GFRP layers. The GFRP material which was equal in length to the panel dimensions, was glued onto it by a roller. After the hand lay-up process, bonding and simultaneous curing of fiberglass overlays to the core layer was made in a press applying 0.2 MPa pressure at ambient temperature for 24 hours.

Paper overlaid insulation panels were prepared in a one-step process, since paper sheets were hot pressed simultaneously onto the mat layer of bark particles. Paper sheets were applied to the bottom and upper surfaces during the manual formation of the panels. An identical UF resin mixture as used in the bark particles, was spread on the surface of papers using a brush before they were heat compressed.

3. The fiberglass meshes were placed under the surfaces of the panels around 2 mm from both surfaces.

4. The randomly oriented, chopped glass fibres with the prepared lengths were added and homogenized with the bark particles and adhesive in a laboratory type blender for five minutes, before pressing.

5. Panels from heat-treated bark particles were manufactured the same way as the control panels, see point 1.

Thermal conductivity was measured across the thickness of the panel by a heat flow meter using a controlled hot-plate apparatus. The thermal conductivity can be calculated at steady state conditions by measuring the heat flux.

Bulk density (ρ) was measured on the same samples used for the mechanical tests, as the average of at least fifteen specimens. The density of each panel was individually measured at current moisture content at the time of the mechanical bending test.

Dimensional stability of the specimens regarding thickness swelling (TS) and water absorption (WA) after immersion in water for 2 and 24 hours was calculated according to European standard EN 317 [1993]. Twelve specimens with 50×50 mm dimensions were weighed and their thicknesses were measured with a level of accuracy of 0.01 g and 0.1 mm, respectively.

The standard mechanical properties of bark-based panels were characterized using a universal testing machine, Instron 5506, according to the appropriate European Standards. These include bending strength and modulus of elasticity (EN 310), and surface soundness (SS) test to assess the quality of bonding between the overlaid mats and bark-based core layer (EN 311). The tensile strength perpendicular to the surface (internal bond, IB) was determined according to EN 319:1993. The specimens were prepared from different areas of the board and cut according to EN 326-1 European standard.

The analysis of variance (ANOVA) was applied using Statistica13 software (TIBCO Software Inc., USA) to statistically evaluate the influence of the reinforcements. Analysis was done only inside the groups. All data were checked for normality (Shapiro – Wilk test) and homogeneity of variance (Levene's test), at 5% significance level. Post hoc tests were conducted with Tukey's HSD test method.

Measurement results and standard deviations are shown in Tables 4 and 5. The density of most of the panels was higher than the target density (350 kg/m^3), and ranged from 336 to 413 kg/m^3, which is due to the inhomogeneity of the laboratory conditions. Since the surface fiberglass reinforcements were subsequently glued to the previously made panels, their density is significantly higher than that of the other panels. The same amount of starting material was used in the production of the panels made of heat-treated raw material, and the target density was the same (350 kg/m^3), so differences in density are due to laboratory conditions. The density of the panels made of treated bark 1, 2 and 3 hours and the control panels were 336, 349, 352, and 336 kg/m^3 respectively.

The thermal conductivity of the control panels was 0.067 W/m·K and the conductivity of the reinforced panels ranged from 0.067 to 0.078 W/mK. It is known that the thermal conductivity is strongly influenced by the density of the wood panels, because the amount of the solid content increases with density and heat can be transferred in such panels by heat bridges between the particles. The graph (Figure), shows that not only the density influences the thermal conductivity, but also the panel type has a great influence on it. Within a panel type, density does affect thermal conductivity, but the extent of this (slope of the line) varies between types. It should be noted, however, that due to the small number of measurement points, this cannot be stated with absolute certainty. The thermal conductivity of the reinforced panels was not statistically significantly different, even though the mean values of the reinforced panels were different.

Table 4

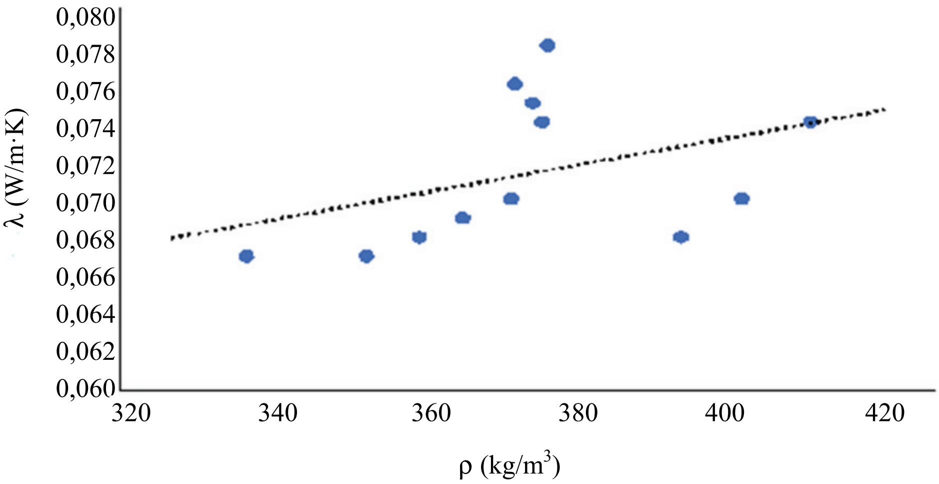
The physical and mechanical properties of panels, pretreated for different durations (T1, T2, T3 = 1, 2, 3 hours) and control (C)

Properties	C	T1	T2	T3
Physical properties:				
ρ, kg/m^3	336.80 (±22.95)	336.40 (±13.53)	349.78 (±20.73)	352.29 (±12.74)
EMC, %	8.88 (±0.22)	8.33 (±0.22)	8.44 (±0.21)	7.66 (±0.17)
WA, wt %	217.89 (±48.0)	185.57 (±23.58)	123.19 (±25.93)	100.61 (±34.82)
T, %	18.18 (±3.09)	10.68 (±2.49)	7.65 (±1.49)	5.45 (±0.72)
Thermal properties:				
λ, W/m·K	0.067 (±0.004)	0.064 (±0.003)	0.065 (±0.005)	0.067 (±0.001)
Mechanical properties:				
MOR, MPa	0.54 (±0.17)	0.45 (±0.09)	0.89 (±0.21)	1.08 (±0.22)
MOE, GPa	0.28 (±0.08)	0.22 (±0.03)	0.41 (±0.13)	0.56 (±.06)
IB, MPa	0.037 (±0.014)	0.032 (±0.018)	0.039 (±0.009)	0.047 (±0.014)

Table 5

Properties of the glass fiber reinforced panels and control panels

Properties	Control	P1	P2	GFRP1	GFRP2	GFRP3	GF_12	GF_18	GF_24	GF_30	M1	M2
Physical properties: ρ, kg/m^3	336.80 (±22.95)	360.24 (±17.57)	353.06 (±14.67)	413.07 (±23.77)	395.69 (±18.66)	403.71 (±26.97)	376.89 (±19.46)	375.60 (±14.82)	377.63 (±12.47)	373.21 (±15.80)	372.68 (±30.93)	366.14 (±10.90)
EMC, %	8.88 (±0.17)	9.12 (±0.15)	9.60 (±0.36)	9.29 (±0.28)	9.51 (±0.56)	9.64 (±0.23)	9.66 (± 0.84)	10.18 (± 0.09)	9.86 (± 0.27)	9.58 (± 0.28)	9.66 (±0.30)	9.43 (±0.30)
WA, wt %	218.37 (±28.03)	159.32 (±6.98)	210.87 (±42.45)	147.03 (±24.04)	161.34 (±23.53)	152.83 (±22.96)	193.23 (±28.05)	173.87 (±16.91)	177.54 (±18.29)	190.94 (±26.26)	207.61 (±35.91)	182.73 (±8.37)
TS, %	18.18 (±3.09)	12.39 (±0.86)	16.90 (±2.40)	13.76 (±2.90)	9.78 (±2.14)	9.63 (±1.37)	8.88 (±1.12)	9.18 (±0.80)	9.14 (±1.15)	9.28 (±0.88)	16.83 (±2.62)	15.83 (± 1.43)
Thermal properties: λ, W/m·K	0.067 (±0.004)	0.068 (± 0.001)	0.067 (±0.004)	0.074 (±0.002)	0.068 (±0.001)	0.070 (±0.004)	0.074 (±0.007)	0.075 (±0.002)	0.078 (±0.004)	0.076 (±0.002)	0.070 (±0.004)	0.069 (±0.001)
Mechanical properties: SS, N/mm^2	–	0.12 (±0.07)	0.08 (±0.05)	0.16 (±0.06)	0.17 (±0.04)	0.23 (±0.10)	–	–	–	–	–	–
IB, N/mm^2	0.04 (±0.02)	–	–	–	–	–	0.13 (± 0.02)	0.10 (± 0.03)	0.09 (± 0.01)	0.12 (± 0.03)	0.04 (±0.01)	0.05 (±0.02)
MOR, MPa	0.54 (±0.17)	2.21 (±0.29)	1.43 (±0.24)	2.54 (±0.81)	2.82 (±0.68)	4.45 (±1.98)	1.02 (±0.21)	0.84 (±0.18)	0.75 (±0.22)	0.66 (±0.19)	0.54 (±0.17)	2.44 (±0.65)
MOE, GPa	0.28 (±0.08)	0.99 (±0.10)	0.66 (±0.06)	1.95 (±0.40)	1.36 (±0.19)	2.86 (±0.48)	0.19 (±0.03)	0.15 (±0.02)	0.15 (±0.02)	0.15 (±0.03)	0.28 (±0.08)	0.66 (±0.11)



Relation between density and thermal conductivity of the glass fiber reinforced panels

The density of most of the panels was higher than the target density (350 kg/m^3), and ranged from 336 to 413 kg/m^3, which is due to the inhomogeneity of the laboratory conditions. Since the surface fiberglass reinforcements were subsequently glued to the previously made panels, their density is significantly higher than that of the other panels.

The same amount of starting material was used in the production of the panels made of heat-treated raw material, and the target density was the same (350 kg/m^3), so differences in density are due to laboratory conditions. The density of the panels made of treated bark 1, 2 and 3 hours and the control panels were 336, 349, 352, and 336 kg/m^3 respectively.

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forced panels ranged from 0.067 to 0.078 W/m·K. It is known that the thermal conductivity is strongly influenced by the density of the wood panels, because the amount of the solid content increases with density and heat can be transferred in such panels by heat bridges between the particles. The graph (Figure), shows that not only the density influences the thermal conductivity, but also the panel type has a great influence on it. Within a panel type, density does affect thermal conductivity, but the extent of this (slope of the line) varies between types. It should be noted, however, that due to the small number of measurement points, this cannot be stated with absolute certainty. The thermal conductivity of the reinforced panels was not statistically significantly different, even though the mean values of the reinforced panels were different.

The thermal conductivity of the panels was 0.064, 0.065 and 0.067 W/m·K respectively, and the control panels had 0.067 W/m·K. Parallel to the increasing density of the panels, the thermal conductivity of the panels made of treated bark particles increased. The control and the T1 panels had a similar density, but the treated panels had lower thermal conductivity, because the thermal treatment changed the cell walls of the particles by changing their molecular structure and due to weight loss, small cavities or voids are formed in the cell wall and decreased the EMC of the panels, which also influence their thermal conductivity. Since we produced panels of almost the same density from heat-treated materials and these panels have lower thermal conductivity at the same density (T1), and reach the value of control panels at about 5% higher density (T3), it shows that the heat treatment had an effect on the microstructure and chemical levels, but the density of the panels had a greater impact on their thermal conductivity than the heat-treatment. The difference between the treatments was not statistically significant.

Physical properties. The EMC of the glass fiber and paper reinforced boards was not significantly different from the control panels. All the panels made of treated bark had a lower EMC than the controls. With increasing treatment time, the EMC decreased, because of the heat degraded the hydroxyl groups of the hemicelluloses, which is one of the major hygroscopic components of wood. The Tukey-test grouped T1 and T2 and put T3 in an individual group.

The application of fiberglass and epoxy resin bonding on the surfaces of bark-based panels, significantly reduced the water absorption and thickness swelling, due to its water vapor resistance compared to the control boards, but there were no significant differences between the glass overlaid boards. With paper coating, the lower contact angle (CA) and negative immersion wetting calculation (ΔGi) values observed on the glued surface of the recycled paper indicate the most favorable wettability. This results the significantly lower WA and TS. The inner mesh reinforcement and glass fiber reinforcement of the panels did not significantly affect the water uptake and thickness swelling of the bark boards. Both the WA and TS decreased in parallel with the duration of the treatment. Both the WA and TS decreased parallel with the duration of the pretreatment of the bark raw material. The control and T1 form a group based on the WA, the T2 and T3 form another group based on both the WA and the TS.

The flexural strength and modulus, as well as surface soundness were significantly influenced by the type of overlaying material. As a general conclusion, it can be stated that the mechanical properties of fiberglass overlaid panels, had improved values compared to paper overlaid mats. Of the two paper types, recycled paper sheets had enhanced mechanical properties compared to the coated TMP paper sheets. Nevertheless, none of these paper sheet types resulted in adequate measurements. This was also true for with water absorption and thickness swelling values. On the other hand, fiberglass woven fabric exhibited the best performance compared to that of fiberglass mesh and mat and, similar mechanical properties were obtained for both fiberglass mesh and mat types. GFRP3 fiberglass type samples had the lowest thermal conductivity values, the lowest water.

Immersion properties and the highest mechanical properties of all the panels. The control boards had higher MOR and MOE values compared to the bark boards reinforced with 12–30 mm glass fiber. Further, the MOR and MOE were shown to decrease by increasing the fiber length from 12 to 30 mm. The boards reinforced with a glass fiber 12 mm long showed the best mechanical performance, of the fiber lengths that were tested. There was no significant difference in the IB inside the reinforcement groups, but differences can be observed between the inner mesh and glass fiber reinforcement: the inner mesh reinforced boards had a lower IB. This may be due to the fact that no chemical bond was formed between the glass fiber reinforcement and the bark particles, so that delamination was often observed during the measurement.

The mechanical properties of the boards made of heat treated raw material are similar, no significant differences were observed.

Conclusions. The first conclusion is that it is possible to produce thermal insulation panels from Pannonia poplar bark using UF resin.

Because the thermal conductivity of different wood-based panels ranged from 0.05 to 0.08 W/m·K, the thermal conductivity of the boards we manufactured was in the upper half of this range. Although the thermal conductivity of artificial insulating materials is between 0.021 and 0.045 W/m·K, and the environmental impact of naturally-based insulation is much lower. The heat treatment had an effect on thermal conductivity, but the density dependence of heat conduction obscured the effect of heat treatment. By using heat-resistant adhesives post-manufacture heat treatment of the finished panels could be used and the density and thermal conductivity of the panels could be drastically reduced.

Although the insulating materials do not have to have as high bending strength as structural elements, it can be an advantage during transport and handling of the insulating material if our insulating material has some rigidity. The strength of the bark board can be improved by reinforcements. Almost all the reinforcements improved the strength properties to some extent. The glass fiber woven fabric overlaid boards had the best properties among the boards. In some cases, the results could be further improved by using an adhesive that forms a bond between the fiberglass and bark particles.

Reinforcements only had an effect on physical properties (EMC, WA, TS) if they physically prevented the board from absorbing water. The heat-treatment of the raw material changed the chemical structure, thus decreasing the water absorption and swelling of the manufactured panels.

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References

1. Pavel C. C., Blagoeva D. T. Competitive landscape of the EU's insulation materials industry for energy-efficient buildings. Luxemburg, Publications Office of the European Union, 2018. 24 p.

2. Zhou X., Zheng F., Li H., Lu C. An environment-friendly thermal insulation material from cotton stalk fibers. *Energy and Buildings*, 2010, no. 42, pp. 1070–1074.

3. Volf M., Diviš J., Havlíka F. Thermal, moisture and biological behavior of natural insulating materials. *Energy Procedia*, 2015, no. 78, pp. 1599–1604.

4. Schiavoni S., D'Alessandro F., Bianchi F., Asdrubali F. Insulation materials for the building sector: A review and comparative analysis. *Renewable and Sustainable Energy Reviews*, 2016, no. 62, pp. 988–1011.

5. Pásztory Z., Mohácsiné R. I., Börcsök Z. Investigation of thermal insulation panels made of black locust tree bark. *Construction and Building Materials*, 2017, no. 147, pp. 733–735.

6. Aydin I., Demirkir C., Colak S., Colakoglu G. Utilization of bark flours as additive in plywood manufacturing. *Eur. J. Wood Prod*., 2017, no. 75, pp. 63–69.

7. Murphey W. K., Rishel L. E. Relative strength of boards made from bark of several species. *Forest Products Journal*, 1969, no. 19, pp. 52.

8. Yemele M. C. N., Blanchet P., Cloutier A., Koubaa A. Effects of bark content and particle geometry on the physical and mechanical properties of particleboard made from black spruce and trembling aspen bark. *Forest Products Journal*, 2008, no. 58, pp. 48–56.

9. Maloney T. M. Bark boards from four west coast softwood species. *Forest Products Journal*, 1973, no. 23, pp. 30–38.

10. Nemli G., Çolakoğlu G. Effects of mimosa bark usage on some properties of particleboard. *Turkish Journal of Agriculture and Forestry*, 2005, no. 29, pp. 227–230.

11. Cai Z. Selected properties of MDF and flakeboard overlaid with fibreglass mats. *For. Prod. Journal*, 2006, no. 56, pp. 142–146.

12. Biblis E. J., Carino H. F. Flexural properties of southern pine plywood overlaid with fibreglass-reinforced plastic. *For. Prod. Journal*, 2006, no. 50, pp. 34–36.

13. Moradpour P., Pirayesh H., Gerami M., Jouybari I. R. Laminated strand lumber (LSL) reinforced by GFRP; mechanical and physical properties. *Constr. Build. Mater*., 2018, no. 158, pp. 236–242.

14. Bal B. C. Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber. *Constr. Build. Mater*., 2014, no. 51, pp. 9–14.

15. Kizilkanat A. B., Kabay N., Akyüncü V., Chowdhury S., Akça A. H. Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study. *Constr. Build. Mater.*, 2015, no. 100, pp. 218–224.

16. Zolfagari A., Behravesh A. H., Shahi P. Comparison of mechanical properties of wood-plastic composites reinforced with continuous and noncontinuous glass fibers. *Journal of Thermoplastic Composite Materials*, 2015, no. 28, pp. 791–805.

17. Maclean J. D. Thermal conductivity of wood. *Heating, Piping & Air Conditioning*, 1941, no. 13, pp. 380–391.

18. Seborg R. M., Tarkow H., Stamm A. J. Effect of heat upon the dimensional stabilization of wood. *Journal of Forest Product Res. Soc*., 1973, no. 3, pp. 59–67.

19. Korkut S., Aytin A., Taşdemír Ç., Gurău L. The transverse thermal conductivity coefficients of Wild cherry wood heat-treated using the Thermo Wood method. *ProLigno*, 2013, no. 9, pp. 649–683.

Список литературы

1. Pavel C. C., Blagoeva D. T. Competitive landscape of the EU's insulation materials industry for energy-efficient buildings. Luxemburg: Publications Office of the European Union, 2018. 24 p.

2. An environment-friendly thermal insulation material from cotton stalk fibers / X. Zhou [et al.] // Energy and Buildings. 2010. No. 42. P. 1070–1074.

3. Volf M., Diviš J., Havlíka F. Thermal, moisture and biological behavior of natural insulating materials // Energy Procedia. 2015. No. 78. P. 1599–1604.

4. Insulation materials for the building sector: A review and comparative analysis / S. Schiavoni [et al.] // Renewable and Sustainable Energy Reviews. 2016. No. 62. P. 988–1011.

5. Pásztory Z., Mohácsiné R. I., Börcsök Z. Investigation of thermal insulation panels made of black locust tree bark // Construction and Building Materials. 2017. No. 147. P. 733–735.

6. Utilization of bark flours as additive in plywood manufacturing / I. Aydin [et al.] // Eur. J. Wood Prod. 2017. No. 75. P. 63–69.

7. Murphey W. K., Rishel L. E. Relative strength of boards made from bark of several species // Forest Products Journal. 1969. No. 19. P. 52.

8. Effects of bark content and particle geometry on the physical and mechanical properties of particleboard made from black spruce and trembling aspen bark / M. C. N. Yemele [et al.] // Forest Products Journal. 2008. No. 58. P. 48–56.

9. Maloney T. M. Bark boards from four west coast softwood species // Forest Products Journal. 1973, No. 23. P. 30–38.

10. Nemli G., Çolakoğlu G. Effects of mimosa bark usage on some properties of particleboard // Turkish Journal of Agriculture and Forestry. 2005. No. 29. P. 227–230.

11. Cai Z. Selected properties of MDF and flakeboard overlaid with fibreglass mats // For. Prod. Journal. 2006. No. 56. P. 142–146.

12. Biblis E. J., Carino H. F. Flexural properties of southern pine plywood overlaid with fibreglass-reinforced plastic // For. Prod. Journal. 2006. No. 50. P. 34–36.

13. Laminated strand lumber (LSL) reinforced by GFRP; mechanical and physical properties / P. Moradpour [et al.] // Constr. Build. Mater. 2018. No. 158. P. 236–242.
14. Bal B. C. Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber // Constr. Build. Mater. 2014. No. 51. P. 9–14.
15. Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study / A. B. Kizilkanat [et al.] // Constr. Build. Mater. 2015. No. 100. P. 218–224.
16. Zolfagari A., Behravesh A. H., Shahi P. Comparison of mechanical properties of wood-plastic composites reinforced with continuous and noncontinuous glass fibers // Journal of Thermoplastic Composite Materials. 2015. No. 28. P. 791–805.
17. Maclean J. D. Thermal conductivity of wood // Heating, piping & air conditioning. 1941. No. 13. P. 380–391.
18. Seborg R. M., Tarkow H., Stamm A. J. Effect of heat upon the dimensional stabilization of wood // Journal of Forest Product Res. Soc. 1953. No. 3. P. 59–67.
19. The transverse thermal conductivity coefficients of Wild cherry wood heat-treated using the Thermo Wood method / S. Korkut [et al.] // ProLigno. 2013. No. 9. P. 649–683.

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