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INTERNAL FIBERGLASS MESH REINFORCED BARK-BASED PANELS

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ABSTRACT

One-layer bark panels were internally reinforced with two different grid sizes fiberglass mesh sheets (M1 and M2). The thermal conductivity, water absorption, thickness swelling, static bending properties and internal bond strength of these panels were tested. The reinforcement doesn't affect the thermal conductivity, but the physical and mechanical properties of the panel were improved. The thickness swelling was reduced by 7.43% and 12.93%; the water uptake decreased by 4.93% and 16.32% for the M1 and M2 sheets, respectively. MOR increased from 0.54 MPa to 2.44 and 2.1 MPa, and MOE increased from 0.28 GPa to 0.66 and 0.63 GPa, respectively. The internal bond didn't change. The findings indicate that it is possible to produce internal reinforced bark panels for insulation materials depending on the characteristics and tensile properties of the reinforcing materials, as well as the adhesion properties and interfacial interaction of the composite materials.

KEYWORDS: Bark, insulation, glass fiber reinforced panels, thermal conductivity, mechanical properties.

INTRODUCTION

The utilization of waste materials produced on the forestry and silviculture sector, such as agricultural and bark residues is always in high demand. For instance, the quantity of bark produced annually is estimated to be approximately 359,114,200 m^3 (FAO 2015). Past research efforts have been investigated bark as a feedstock material for the manufacturing of different type of panels such as particleboards, hardboard, medium density fiberboard and oriented strand board (Pedieu et al. 2008).

The low mechanical performance has prevented the use of bark on the manufacturing engineered wood panels. However, other type of panels like insulation boards does not need to meet similar requirements or require such a high strength (Maloney 1973).

Due to inadequate mechanical properties, surface reinforcements were first applied to solid wood, and in particular beams were reinforced by this method. Fiberglass mat, cloth, and strands can all be used for reinforcement for beams, but the strands provide the greatest tensile strength (Theakston 1965). Boehme and Schulz (1974) sheeted wood particleboard, plywood and solid wood with glass fiber-reinforced plastic layers in a wet process. A remarkable increase of strength and stiffness, a reduced creep ratio was observed. Applying glass yarn scrim to the surface of the hardboard effectively improved strength, stiffness, and linear stability of the medium-density boards and hardboards (Steinmetz 1977). Spaun (1981) made composite members with solid western hemlock cores and Douglas-fir veneer and fiberglass layers sandwiched on both sides. Both the veneer and fiberglass provided significant reinforcement to the hemlock cores. Rowlands et al. (1986) stated that adding fiber reinforcement to wood increased strength, stiffness, and engineering toughness, while potentially decreasing mechanical variability. Fiber reinforcement should be used in regions of stress concentration, as well as with tensile and flexural members. Cheng (1996) used glass fiber reinforcement on glulam beams. The strength of the reinforced specimens increased. Cai (2006) examined the effect of fiberglass reinforcement on mechanical and physical properties of MDF and flakeboard. The reinforcement of fiberglass on the surface of MDF and flakeboard improved MOE and MOR and the resistance to TS and WA. Wang et al. (2009) investigated flakeboards reinforced with bamboo strips. The MOR and MOE were substantially greater for all three experimental panel types as compared to the control group. The bamboo strip alignment patterns had no significant effect on thickness swelling, water absorption and internal bond, but affected the other mechanical properties. Barbosa et al. (2015) glued bamboo laminas on three-layer medium density particleboard. The reinforcements increased the mechanical properties of the eucalyptus particleboards. Three-layered particleboards were manufactured from wood, hurd and shive particle and reinforced in the upper and lower face layers with aligned flax and hemp fiber mats (Sam-Brew and Smith 2015). The bending strength properties were improved; the thickness swelling and water absorption properties were also significantly reduced.

A special type of the surface reinforcement is the lamination. Nemli and Çolakoğlu (2005) coated particleboards with papers, veneers and press laminates and improved the mechanical properties, decreased the thickness swelling and formaldehyde emission. Bardak et al. (2011) improved mechanical properties and abrasion resistance of particleboards by paper overlaying. The mechanical and physical properties of the coated particleboards improved and formaldehyde emission decreased (Liu et al. 2013). Christoforo et al. (2016) also studied the influence of lamination by natural fibers (palm fiber and sisal fiber) and synthetic fibers (glass and carbon fibers) on *Pinus* sp. wood particleboards. In all cases MOE and MOR increased.

The reinforcement can be inside the manufactured product too. Saucier and Holman (1976) developed a method for producing structural members from wood particles and glass fiber was used as continuous filament for reinforcement. It was found that elongated wood flakes were the best for wood particles. Smulski and Ifju (1987) improved the MOE and MOR of a hardboard by internal reinforcement with continuous glass fibers. The effect of metal and woven synthetic nets reinforcement on the mechanical properties of MDF was studied by Mohebby et al. (2011). The reinforcements were placed under the surface. Bending properties and tensile strength were increased due to the reinforcement. Natural materials were also used for internal reinforcement; MOR and MOE of the panels improved almost all cases. For example flax straw mats (Tröger and Ullrich 1994), coconut coir coconut coir (Kavitha et al. 2015), flax fibers (Domier et al. 1991), jute fibers (Deng and Furuno 2002), vine pruning's fibre (Yeniocak et al. 2016) was used for different panel types.

Liu et al. (2013) mixed chopped basalt fibres with different lengths with fir sawdust at several weight fractions to produce basalt fiber reinforced fir sawdust panels. The reinforced panels showed improved strength values.

The challenge for green and thermal energy efficient buildings from natural, nontoxic, renewable and environmental-friendly resources is rising constantly (Korjenic et al. 2011). In recent years, studies on the thermal properties of low density bark (Kain et al. 2013, Pásztory et al. 2017) or agglomerated cork (Barreca and Fichera 2016, Sierra-Pérez et al. 2016) panels have been investigated for use in the building construction.

Fiber-reinforced plastics (FRPs) including glass fibers which are spun into yarns are commonly used materials for the fabrication of FRPs lightweight, structural composites. In order to achieve complex geometric profiles, several methods are used such as winding, braiding, knitting, and weaving. Among them weaving process presents the most favourable advantages (Fazeli et al. 2016). Likewise, and correspondingly to textile manufacturing, weaving process is the interlacing of two sets of yarns i.e. warp and weft. Vertically (lengthwise or parallel to selvedge of the cloth) and horizontally (crosswise to the selvedge of the cloth) passing yarns are denoted as warps and wefts respectively, and intersection points between wefts and warps are called float-points (Schneider et al. 2015, Wadje 2009).

Fiber reinforcement to wood has been found to increase the strength, stiffness, and toughness, of wood materials. From the available synthetic fiber reinforcements, glass fibers (GFRP) is considered technically and economically superior (Rowlands et al. 1986) and have been extensively used to enhance mechanical properties of wood intended for structural and non-structural applications. The purpose of this work was to investigate the effect of different grid sizes fiberglass mesh sheets as internal reinforcing materials into bark panels. The physical, thermal and mechanical properties, i.e. the static bending properties and internal bond of these panels were examined.

MATERIALS AND METHODS

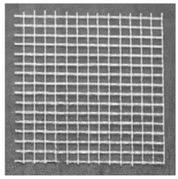
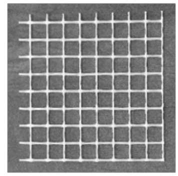
The poplar (*Populus* sp.) bark slabs without separation of inner- and outer-bark, peeled off from poplar trees at a local sawmill, in Sopron, Hungary, were used as raw material for panels production (Fig. 1).

Fig. 1: Preparation of panels with mesh sheets (red arrows) and the manufactured panels.

The bark slabs were size reduced and chopped into particles using a hammer mill equipped with an 8-mm screening holes. Afterwards, the gathered bark particles were fractionated (3 PRO Fritsch Analysette) with different sieves and dried up until a final moisture content of 6-9% was reached. Barks particles ranging from 0.5 mm to 8 mm were collected for the manufacturing of bark-based panels.

Two fiberglass mesh sheets with different grid size (M1 and M2, respectively) suitable as reinforcement materials were supplied by Tolnatext Bt. (Tolna, Hungary). Their main characteristics are given in Tab. 1.

Tab. 1: Basic properties of fiberglass meshes used in this work.

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

A 4% urea-formaldehyde resin DUKOL Ostrava s.r.o. (Kronores CB 1104 D) was used for the production of core-layer bark-based panels. Aqueous solution (35%) of ammonium sulfate as hardener (3% solid content) was added to catalyse the resin curing. The resin/bark particles mixture was formed into a wood frame mould; the mixture was manually pre-compacted and then the frame was removed. The fiberglass meshes were placed interior to the panels around 2 mm from each side, on both surfaces. Bark based insulation panels with a size of 500 × 500 mm, a nominal thickness of 20 mm and a target density of 350 $kg \cdot m^{-3}$ were produced using a laboratory hot press (Siempelkamp). The pressing time was 18 sec per final thickness in mm, and the temperature of the plates was 180°C.

Thermal conductivity was measured across the thickness of the panel using a heat flow meter using a guarded custom made hot-plate apparatus. The thermal conductivity can be calculated at steady state conditions by measuring the heat flux, as described by Fourier's law, according to the following equation:

$$\lambda = \frac{d \cdot \phi_q}{\Delta T} \quad (W \cdot m^{-1} \cdot K^{-1}) \tag{1}$$

where λ is the thermal conductivity measured in watts per meter kelvin ($W \cdot m^{-1} \cdot K^{-1}$), Φ_q is the heat flux ($W \cdot m^{-2}$), ΔT is the temperature difference across the specimen (K) and d is the thickness of the specimen (m).

The temperature difference between the hot and a cold plate was set to 10°C by the mean temperature was 10°C. For each panel type, thermal conductivity test was carried out on three specimens.

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 time of mechanical bending test (EN 323, 1993).

Dimensional stability of the specimens regarding thickness swelling (TS) and water absorption (WA) after immersion in water for 2 and 24 h were calculated according to European standard EN 317 (1993). Sized 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. WA and thickness swelling percentages were estimates as follows:

$$WA\ (\%) = \frac{wetweight - dryweight}{dryweight} \cdot 100 \tag{2}$$

$$\text{TS (\%)} = \frac{d_2 - d_1}{d_1} \cdot 100 \tag{3}$$

where wet weight and d_2 is the weight and thickness of the specimens after 24 h immersion in water, while dry weight and d_1 their initial weight and thickness at equilibrium moisture content, respectively.

The bending strength (MOR) and modulus of elasticity (MOE) of obtained bark-based panels were characterized flatwise, using a universal testing machine Instron 5506 (three-point bending), in compliance with the appropriate European Standards EN 310 (1993) at a speed of 10 mm·min^{-1}. Fig. 2 shows the loading scheme was used, red lines show the meshes under the surfaces of the specimen.

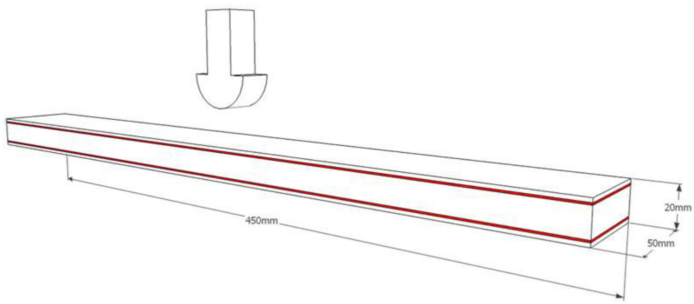


Fig. 2: The loading scheme of MOR and MOE. Red line is the mesh under the surfaces of the specimen.

MOR and MOE were calculated according to the following equations:

$$\text{MOR} = \frac{3 \cdot F_{max} \cdot L}{2 \cdot b \cdot d^2} \tag{4}$$

$$\text{MOE} = \frac{\Delta F}{\Delta \alpha} \cdot \frac{L^3}{4 \cdot b \cdot d^3} \tag{5}$$

where F_{max} is the maximum force at the time of rupture (N), L is the span between supports (mm), b is the width of the specimens (mm), and d is the thickness of the specimens (mm), ΔF is the load increment and $\Delta\alpha$ is the deflection increment rate.

The tensile strength perpendicular to the surface (internal bond) was determined by using 50 × 50 mm specimens from each panel according to EN 319 (1993), at a speed of 0.06 mm·min^{-1}. The maximum force (F_{max}) was calculated and internal bond strength (IB) was estimated using the following formula:

$$\text{IB} = \frac{F_{max}}{b\ l} \tag{6}$$

where b and l are the width and the length of the specimens (mm), respectively.

In order to evaluate the differences between a one-way ANOVA analysis was performed using the Statistica13 software. All data were checked for normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test). Post hoc tests were conducted with Tukey's HSD test method.

RESULTS AND DISCUSSION

The results of the physical, thermal and mechanical characterizations are presented in Tab. 2.

Tab. 2: Physical, thermal and mechanical properties of internal reinforced bark-based panels, with fiberglass mesh sheets.

	Control	M1	M2
Physical properties			
ρ (kg·m^{-3})	336.80 (±22.95)	372.68 (±30.93)	366.14 (±10.90)
EMC (%)	8.88 (±0.17)	9.66 (±0.30)	9.43 (±0.30)
WA (wt%)	218.37 (±28.03)	207.61 (±35.91)	182.73 (±18.37)
TS (%)	18.18 (±3.09)	16.83 (±2.62)	15.83 (±1.43)
Thermal properties			
λ (W·m^{-1}·K^{-1})	0.067 (±0.004)	0.070 (±0.004)	0.069 (±0.001)
Mechanical properties			
IB (N·mm^{-2})	0.04 (±0.01)	0.05 (±0.02)	0.04 (±0.02)
MOR (MPa)	0.54 (±0.17)	2.44 (±0.65)	2.10 (±0.31)
MOE (GPa)	0.28 (±0.08)	0.66 (±0.11)	0.63 (±0.07)

As expected, the bulk density of the reinforced panels was increased, due to the additional layers of fiberglass sheets on both surfaces of the bark panels. Average moisture content of all tested specimens was 9.32%, ranging between 8.9% and 9.7%. The thermal conductivity values were found not to be statistically significant different, even though the mean values of the reinforced panels were indicated to be slightly increased from 0.067 to 0.070 W·m^{-1}K^{-1}.

In terms of static bending properties, MOR and MOE of reinforced bark panels displayed improved performance than control specimens. The mean MOR of the M1 and M2 specimens was 2.44 MPa and 2.10 MPa, respectively. Additionally, the MOE and IB values were observed to be, around 0.65 GPa and 0.05 N·mm^{-2}, respectively. The IB strength was found to be similar and fairly low, including both reinforced and unreinforced panels. IB is considered to be related to the weak binding strength points within a composite (Cai 2006). During the IB test, almost all the examined specimens were failed in the surface layer of the panel, near the area of fiberglass sheets. The fiberglass meshes sheets, were assumed potentially not to improve IB values, since these were simply internally positioned and bonded together under hot pressing with the low resin (4% UF) glued bark particles.

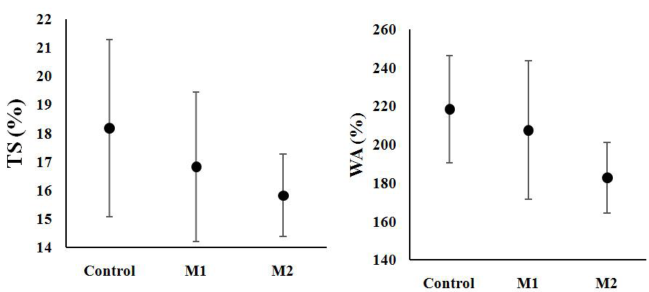


Fig. 3: TS (%) and WA (%) values of the internal reinforced and unreinforced bark panels.

As for thickness swelling, the highest values were obtained from the unreinforced panels, while lower values were observed for M1 and M2 panels (7.43% and 12.93%), respectively. Likewise, the WA values of the reinforced panels were also decreased by 4.93% and 16.32% for the M1 and M2 sheets, respectively. This behavior may be explained, as it is already suggested in compliance with the tensile strength differences between the used fiberglass sheets. Although, in this case TS values were not statistically significant different related to the unreinforced specimens (Fig. 3). However, WA of the M2 fiberglass was found to be significant lower compared to control specimens. Nevertheless, it seems that reinforced materials tended to slightly inhibit the water absorption and as a consequence to restrain the swelling of the bark panels.

In general, the panels reinforced with the lower grid size mesh (M1) exhibited higher variations in most of the physical and mechanical properties, such as MOR and TS compared to the higher grid size (M2) mesh panels. This could be attributed to the higher tensile strength in both warp and weft direction, occurring in the M2 fiberglass sheets. This hypothesis, was further indicated regarding the dimensional stability changes, observed with TS and WA values. However, there were not demonstrated any statistical differences between the proposed fiberglass sheets, as illustrated in Fig. 4.

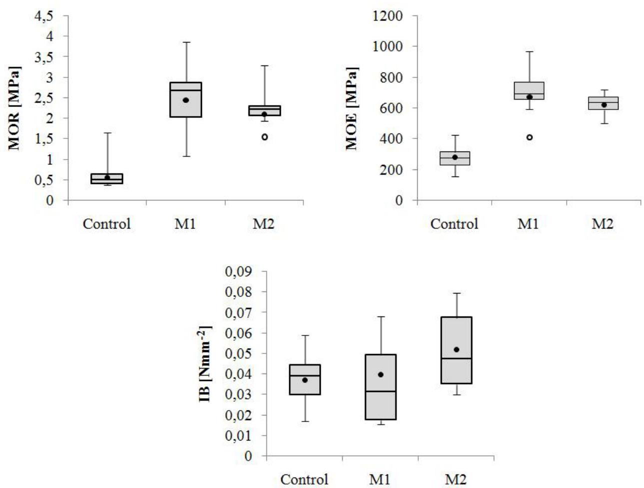


Fig. 4: Mechanical properties (MOR, MOE and IB values) of unreinforced and reinforced bark panels (full circles are the averages, circle outlines are outliers).

Analogous tendency on MOR and MOE values were also indicated by Yeniocal et al. (2016). In their study, they placed cord fabric, plaster mesh and polyester fabric of various densities and sizes, between the surface and core-layer of a three-layer particleboard (10% UF resin, 700 kg·m^{-3}) made of vine pruning waste material. On the contrary in their case, the obtained IB strength values of the reinforced particleboards were ranging from 0.064 to 0.498 N·mm^{-2}.

CONCLUSIONS

The results acquired in this work revealed that the internal reinforced fiberglass mesh sheets affected the mechanical performance of the bark panels. A reasonable improvement on the flexural strength and stiffness values was shown. However, internal bond and thickness swelling values were found to remain low and not significantly differ from the unreinforced specimens. Further research or modifications would be crucial to enhance the observed weak binding strength of the overall composite and improve the adhesion force between the materials. It was also determined that the fiberglass sheet with higher tensile strength and larger grid size presented better performance in total, compared to the other sheet. Finally, the findings on thermal conductivity values, demonstrate that the proposed panels could potentially be used as interior, insulation boards.

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