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THE EFFECT OF TYPE OF WOOD-BASED RECYCLATE AND LOW-QUALITY TIMBER IN PARTICLEBOARD ON MECHANICAL PROPERTIES OF FURNITURE JOINTS

Viktória Satinová – Silvia Jánošíková – Nadežda Langová – Zuzana Vidholdová – Ján Iždinský

ABSTRACT

The effect of particleboard (PB) composition made of recycled or lower-quality timber on the mechanical properties of selected furniture joints is determined in the paper. The tested PBs were manufactured using recycled PB or blockboard from old furniture and lower-quality timber with brown or white rot. The laboratory-produced control PB with particle content of 100% sound spruce wood (*Picea abies Karst. L.*) and commercial PBs were used for comparison of the results. The load capacity and stiffness of corner joints with the confirmat (ø5 × 50 mm) and wooden dowel (ø6 × 30 mm) and the withdrawal resistance and stiffness of the screw (ø3.5 × 30 mm) were tested. The corner joints were loaded under compression by bending moment in the angular plane. In terms of load-carrying capacity, control PB was the most suitable in achieving a load-carrying capacity of 7827.61 N·mm for the confirmat and PB from recycled blockboard 4072.71 N·mm when using the wooden dowel. As for joint stiffness, the best values achieved were 1316.00 N·mm/° and 808.58 N·mm/° for the PB from recycled blockboard using the confirmat and dowel, respectively. PB from recycled blockboard again showed the highest values of screw withdrawal resistance - for the edge withdrawal 416.61 N and for the surface withdrawal 556.44 N. Considering the values found for the investigated mechanical properties, it was assumed that the tested materials can be used as non-load-bearing elements in furniture construction.

Keywords: wooden recyclate; particleboard; furniture joints; joint mechanical properties.

INTRODUCTION

Sustainable product initiatives aim to ensure that by 2030, a significant proportion of products available to consumers in the European Union are designed to be durable, energy and resource-efficient, more environmentally friendly, repairable, and recyclable, and preferably use recycled materials in their production. Eco-design, sometimes referred to as Design for the Environment, is an umbrella term describing techniques used to incorporate an environmental component into products and services before they enter the production phase (Directive 2009/125/EC, Act No. 529/2010 Coll. on Environmental Design and Use of Products) It can be performed by adopting various tools and methods, such as those based on the life cycle thinking principle (ISO 14006: 2020). The design of ecomaterials is changing from the single criterion of environmental consciousness to total life-cycle considerations in the production and use of products. Life-cycle considerations demand checkpoints at three stages of product life: (1) processing stage: from the extraction of resources to the delivery of products; (2) utilization stage: the period during which products are used as intended; and (3) end-of-life stage: recycling or disposal after use (Halada and Yamamoto, 2001). Life cycle thinking is based on core principles of the Life Cycle Assessment (LCA) methodology according to ISO 14044:2020. The LCA techniques showed that particleboards (PBs) have a minimal impact on the environment, except for global warming if they were not landfilled after use (Rivela *et al*., 2006; Mohd Azman *et al.*,2021; Santos *et al.*, 2021). According to the results of the study of Çınar (2005), standard PB had an environmental impact lower than standard fiberboard (72% improvement). For surface and edge finishes, a low-density laminate is preferred to a high-density laminate (36% improvement). Silva *et al.* (2021) investigated the potential of recycled wood and bio-resins to make the PBs. The iterative testing and LCA of PB resulted in the fact that the developed PBs were environmentally benign alternatives to conventional PB made of synthetic polymers and wood particles, reducing up to 95% of the environmental impacts of human toxicity, abiotic depletion, and other impacts compared to conventional practices.

Furniture is an apparatus needed in human daily life. The design and construction of furniture is an applied art. The requirements for furniture design are not only appealing appearance and current fashion but also sound functionality and structural safety (Wang and Lee, 2014).

In furniture manufacturing various materials, such as wood and wood-based panels are used. Wood-based panels such as medium-density fiberboard and PBs are widely used in manufacturing case-type furniture because the mechanical, physical, and surface qualities of the engineered panels are comparable to those of solid woods (Kasal *et al*., 2011). Today, PB is widely used in furniture manufacturing because PB is much cheaper than wood, fiberboards, and plywood (Bardak, 2018). In the past, various sources of wood are used for their production, mainly forest assortments, and secondary sources (edges, cuttings and sawdust). Today, the effort is to use old or recycled wood, or various lignocellulosic materials (Guler *et al.*, 2004; Kwon *et al.*, 2013; Kord *et al.*, 2015; Wronka and Kowaluk, 2019; Iždinský *et al.*, 2020; Iždinský *et al.*, 2021; Wronka and Kowaluk, 2022; Vilkovský *et al.*, 2022; Pelc and Kowaluk, 2023). There is still a need to look for other alternative sources of wood replacement in the production of PBs, such as agricultural residues (*e.g.*, poppy husks, walnut, kiwi prunings, cotton seed hulls, rice straw-wood, vine prunings, pine cone, almond shells, wood flour) and non-wood plant fibers (Kucuktuvek *et al*., 2017).

However, the employment of fiberboard and PB requires a careful approach to the choice of joints connecting construction elements of such furniture (*e.g.*, particular house furniture for sitting). The application of the same connectors and joints as in the case of solid wood may reduce the stiffness and strength of the construction and increase the time of its assembly, *e.g.*, in particular house furniture for sitting (Smardzewski *et al.*, 2015).

Joints fulfil necessary strength, technological, and operational-aesthetic functions in furniture construction. In general, joints are the weakest parts of a given piece of furniture, and furniture durability depends, first and foremost, on their quality (Podskarbi *et al.*, 2016).

Furniture quality is determined by its form, aesthetics, functionality, ergonomy, rigidity, strength, and durability. The strength and durability of furniture are some of the most essential factors determining furniture value (Smardzewski and Majewski, 2013).

Following the analysis of the literature on the mechanical properties of corner joints for furniture purposes, Majewski *et al.* (2020) stated various aspects regarding corner joint rigidity, namely the influence of material density as well as stiffness and rigidity of fasteners; the effect of number of fasteners on joint stiffness; the influence of fastener/joint geometry on joint stiffness; presence, type, and adhesives application technique; the effect of narrow surfaces finishing, use of edge banding, as well as its type and thickness; the effect of a fastener grain orientation changes in relation to the grain direction of the specimen on the pulled-out joint strength; the influence of the back panel assembly method on the strength of the corner joints; the influence of the fasteners mounting force on the joint strength, the effect of the guide holes diameter for screwed-in connectors on the joint strength.

It is very important that the newly created materials are suitable and compatible with the conditions of the furniture use. The aim of the study by Antov *et al.* (2020) was to evaluate the potential of using new eco-friendly recycled wood fibreboard bonded with magnesium lignosulfonate in furniture construction. For this purpose, the bending strength of L-shaped corner joints with mechanical fasteners was determined.

The L-type corner joints made from the developed composites demonstrated significantly lower bending capacity (from 2.5 to 6.5 times) compared to the same joints made from MDF panels. Nevertheless, the new eco-friendly composites can be efficiently utilised as a structural material in non-load-bearing applications.

The withdrawal capacity is based on the composite action between the screw thread of the wood and hence is defined by the wood properties and geometric parameters of the thread (Hoelz *et al*., 2022). For board materials, the position of the fastener relative to the plane of the plate plays a role. The effect of the thread pitch of confirmats in pine wood was evaluated by Sydor *et al.* (2015); they determined little effect on loading capacity for confirmats placed perpendicular to the tangential plane. The load-bearing capacity of confirmats in the tangential plane was 15% higher than in the radial plane. Chen *et al.* (2016) investigated the pullout resistance of bamboo wood screws with higher resistance compared to that of MDF and PB.

In the work of Taj *et al.* (2009), the axial screw withdrawal resistance of a 4.8 mm diameter screw for beech is 2690 N, hornbeam 3000 N and poplar 1750 N. The pullout force value for a 6 mm diameter bolt for beech is 6111 N, oak 5307 N and pine 2975 N (Efe *et al.*, 2004). The materials often used in furniture are not only commercial materials such as MDF and HDF, but sandwich materials giving the opportunity to improve the properties of the structures or to reduce the price can be used. For example, the three-layer board is made as a combination of PB, as the core, and layers of HDF or MDF as outer layers.

Jivkov *et al.* (2017) investigated 10 wood-based sandwich materials and two types of screw, 4 × 40 mm universal screw, and 7 × 50 mm, concluding that the type of wood-based materials (especially the effect of density) has a significant impact on the axial screw withdrawal resistance investigated; there is no correlation between the density of materials and screw withdrawal resistance; the highest withdrawal resistance for both types of screws was in beech plywood (4066 N), OSB, cherry veneered MDF and birch plywood. The lowest values were obtained in PB, a three-layer board with a core of PB sheathed with laminated HDF with a total thickness of 18 mm and MDF. According to this work, the lowest load capacity of the universal screw was in PB (920 N).

Although brown and white rot reduce the mechanical properties of wood, it is still a material that can be used in the production of composite materials. These materials are environmentally friendly and pose no health risk to humans. Since we want to verify the suitability of using PB made of recycled PB and lower quality wood in furniture construction, the aim of this paper is to verify and compare the mechanical properties of the corner joints and the screw withdrawal resistance. The quality of the joints is also evaluated through the type and extent of damage to the joint.

MATERIALS AND METHODS

Manufacturing of PB

In the laboratory conditions at the Technical University in Zvolen, three-layer PB type P2 was produced for interior use. Four variants of PBs and one variant of control PB were produced (Tab. 1). The PBs contained particles from (a) old laminated PB furniture, (b) old veneered blockboard furniture, (c) lower-quality timber spruce wood (*Picea abies*, Kart. L.) with inactive brown rot (*Famitopisi pinicola* /Sw./ P. Karst.), or (d) lower-quality timber spruce wood (*Picea abies*, Kart. L.) with inactive white rot (*Armillaria ostoyae* /Romang. /Herink). The quantity of brown and white rot in timer is analyzed in Satinová *et al.* (2022). Only particles from sound spruce wood species (*Picea abies*, Kart. L.) were used for manufacturing the control PB.

The particles were bonded with urea-formaldehyde (UF) adhesive with hardener and paraffin from KRONOSPAN s.r.o. The adhesive mixture was applied to the particles in a rotary mixing machine. The layered particles were cold-pressed in a low-temperature machine at a pressure of 1 MPa. The pressing was carried out in a CBJ 100-11 press (TOS, Rakovník, Czech Republic) according to a three-stage pressing diagram – maximum pressing plate temperature 240 ºC, maximum specific pressing pressure 5.23 MPa and with a pressing factor of 8 $s \cdot mm^{-1}$.

PBs were subsequently conditioned in an environment with a temperature of 20±2 ºC and a relative humidity of 65±5%. The manufactured boards were 400 × 300 × 16 mm in size. A total of 6 pieces of board-were manufactured for each type. The specimens were cut from the parts prepared this way. The control specimen was made in order to compare the production technology in the laboratory and commercial conditions. The commercial PB was supplied by JAF Holz Slovakia, s.r.o. The raw PB FunderMax E1E05 Homogen was type P2 with a density of 719 $kg \cdot m^{-3}$ (Tab. 1), which is suitable for the interior. An overview of the density of the PB used in the experiment is given in Tab. 1. The density was determined following the requirements of the standard STN EN 323.

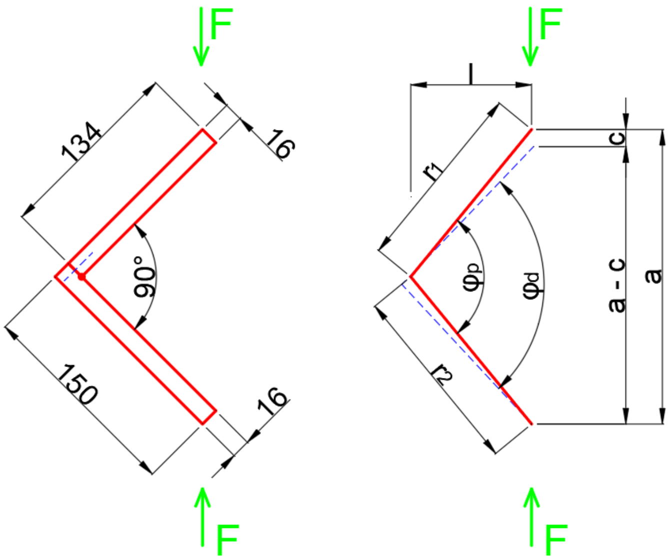
The test specimens of 50 × 150 × 16 mm were stored in an air-conditioned room at a temperature of 20±2 °C and relative humidity of 60±5% for one month. The moisture content of the specimens was determined following the requirements of standard STN EN 322.

Tab. 1 Density of commercial and laboratory manufactured PB used in the experiment.

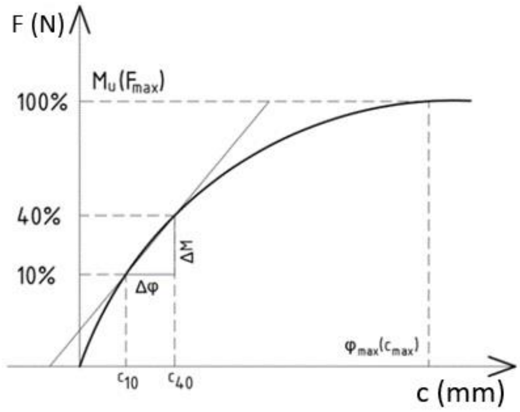
PB types:	Commercial	Control	Recycled PB	Recycled blockboard	Brown rot	White rot
Density ($kg \cdot m^{-3}$)	719 (1.60)	656 (3.46)	643 (3.21)	649 (3.27)	636 (3.60)	640 (3.82)
Moisture content (%)	5.13 (0.21)	6.27 (2.37)	4.96 (0.14)	5.68 (0.34)	5.65 (0.15)	5.89 (0.17)

Determination of the mechanical properties of the corner joints

When determining the load capacity and stiffness of the corner joint, the following scheme (Fig. 1a) for loading the corner joint subjected to bending moment in the angular plane by compression is used. All geometric parameters for determining the mechanical properties of the corner joints can be derived from loading diagram (Figs. 1a and 2b). The load progression of the corner joints was executed according to force deformation diagram (Fig. 1d). Two types of furniture fasteners were tested: a) confirmat with the dimension of ø5 × 50 mm and b) wooden dowel with the dimension of ø6 × 30 mm. The dowels were glued with Technobond polyvinyl acetate adhesive of resistance class D3. It is a one-component copolymer adhesive with good moisture resistance and is suitable for furniture from PB.



(a) **(b)**



(c) **(d)**

Fig. 1 Specimen for stiffness and load capacity (a) dimensions of the specimens, (b) loading scheme with geometrical characteristics (c) execution of the test and (d) force deformation diagram.

r_1, r_2 – arms of the joint, the distance of the center of loading force from the pivot point (mm); l – force arm (mm); F – compression loading force (N); a – arm span (mm); c – displacement of the joint arms under load (mm); φ_p – joint angle before loading (°); φ_d – joint angle after loading (°).

The strength characteristics were investigated in the range from 10% to 40% of the maximum load of the joint. Based on the recorded forces and their associated displacements, the deformation, stiffness and load capacity were calculated using the following equations:

(a) Joint load capacity:

$$M_u = F_{max} \cdot l \qquad (N{\cdot}mm) \qquad (1)$$

(b) Joint stiffness:

$$t = \frac{\Delta M}{\Delta \varphi} \qquad (N{\cdot}mm/°) \qquad (2)$$

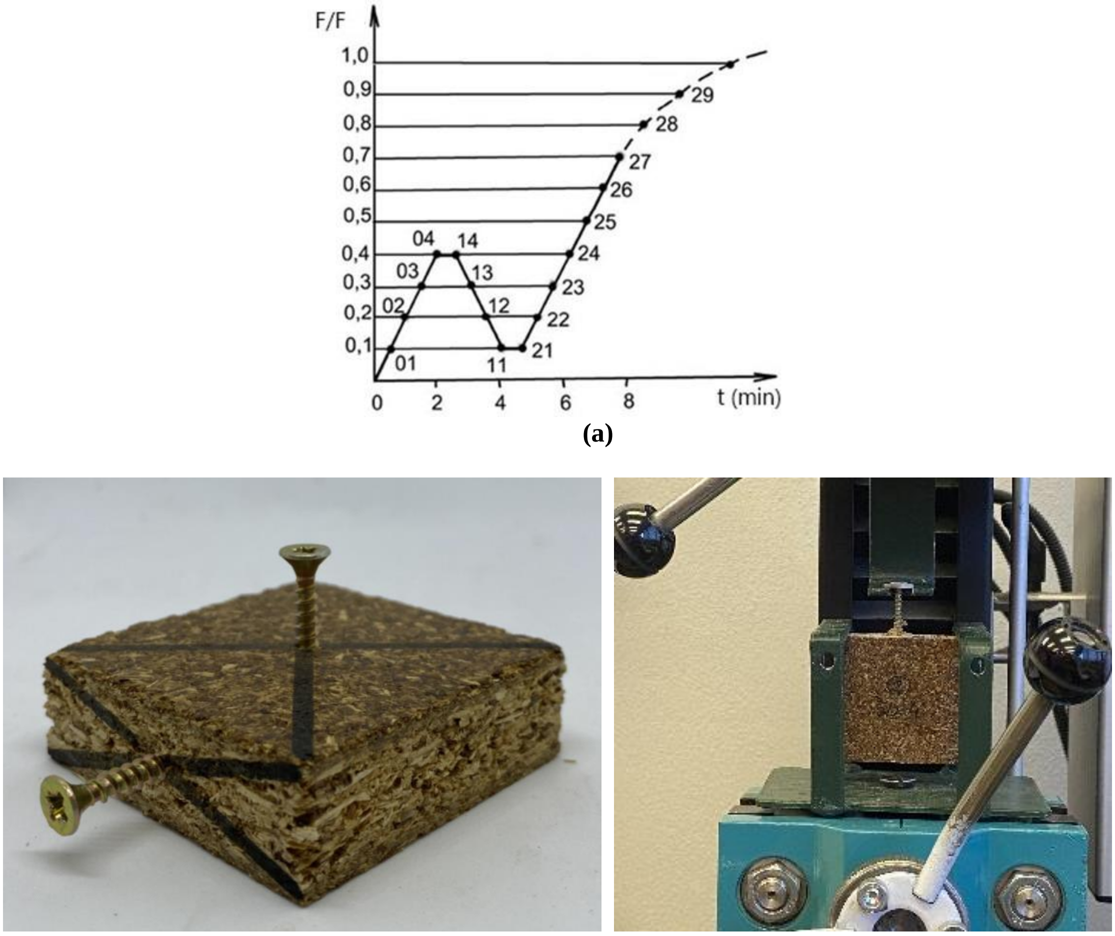
$$\Delta M = 0{,}3 \cdot M_u \qquad (N{\cdot}mm) \qquad (3)$$

$$\Delta\varphi = \varphi_{d10} - \varphi_{d40} \quad (°) \tag{4}$$

Where: M_u – load capacity (N·mm)
F_{max} – maximum loading force (N)
l – arm of the force (mm)
t – joint stiffness (N·mm/°)
Δφ – angular deformation at load from 10% to 40% F_{max} (°).

Determination of the withdrawal capacity and stiffness for the screw

When determining the axial screw withdrawal capacity, the methodology of STN EN 26891:1995 was followed. The test procedure requires estimating the maximum F_{est} load to be determined by experience, calculation, or preliminary tests. The procedure for loading the test body is shown in Fig. 2a. The dimensions of the test specimen for determining the screw withdrawal resistance are w x h x d (mm). The fasteners used in this test were ø3.5 × 30 mm screws. Pre-drilled holes of ø2.5 mm to a depth of 16 mm were drilled at the screw location. The size of the specimens was 50 × 50 mm. The screws were mounted in two directions on the surface and on the edge of the plate as shown in Fig. 2b.



(a)

(b) (c)

Fig. 2 Test procedure for determining the axial withdrawal capacity of the screw, F_{est}, F – loading force, t – duration of the loading (a), screw placement in test body (b), positioning of the specimen in the testing machine (c).

The determined strength characteristics are:

Screw withdrawal capacity: $F_u = F_{max}$ (N)

Deformation at maximum withdrawal capacity: $u = u_{max}$ (mm)

Withdrawal stiffness (modulus of displacement) of the screws in the material (when it is pulled out) expresses the amount of force required to induce a unit length deformation (displacement). It is expressed by the steepness of the force-deflection curve. The withdrawal stiffness of the screw is determined by following equation:

$$T = \frac{\Delta F}{\Delta u} \quad (\text{N·mm}^{-1}) \tag{5}$$

Where: T – withdrawal stiffness (N·mm^{-1}),

ΔF – load capacity difference at 40% and 10% of maximum load (N),

Δu – displacement difference at 40% and 10% of maximum load (mm).

RESULTS AND DISCUSSION

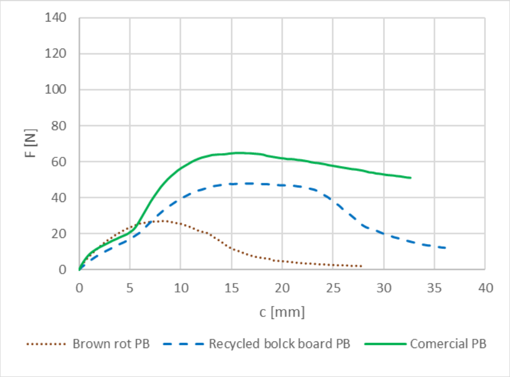
Mechanical properties of the corner joints

The average values of the mechanical properties for corner joints loaded by compressive bending moment for the individual materials and connector types tested, are given in Tab. 2 and 3. The load-carrying capacity M_u (N·mm) and stiffness of corner joints t (N·mm/°) were evaluated. Based on the preliminary tests, it was found that for all materials and dimensions of the confirmat tested, the bending moment stress in the angular plane in tension exhibits a higher load-carrying capacity than the bending moment stress in the angular plane. Both the stiffness and the load capacity of the confirmats reach higher values of mechanical properties compared to pin joints, when stressed in the angular plane by compression. The highest values of these mechanical properties were achieved by the joints for PB with recycled block boards. The load capacity of the pin joint is 33% lower compared to the confirmat. The stiffness of the pin joint is 39% lower compared to the confirmat. Comparing the joints for PB with recycled block board with commercial PB, the commercial PB achieves higher values. The values of mechanical properties for the glued pin joint are smaller by 57% and for the confirmat by 35%.

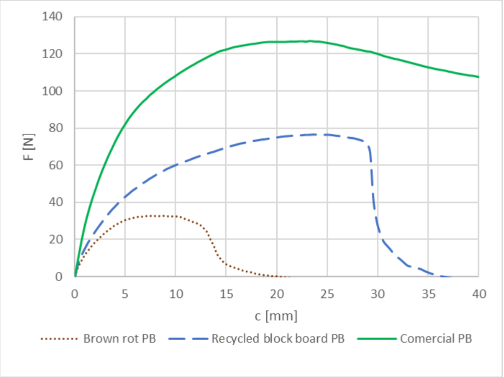
Tab. 2 Mechanical properties of of the corner joint using wooden dowel and confirmat for tested PBs.

	Mechanical properties of corner joint			
	Wooden dowel		Confirmat	
PBs type:	Load-carrying capacity (N·mm)	Stiffness (N·mm/°)	Load-carrying capacity (N·mm)	Stiffness (N·mm/°)
Commercial	5727.46 (13.06)	605.29 (18.52)	10410.06 (8.82)	3105.18 (4.69)
Control	3720.68 (7.01)	711.56 (15.39)	7827.61 (7.45)	2129.81 (14.54)
Recycled PB	2716.44 (11.93)	766.25 (11.41)	3312.32 (20.85)	939.04 (33.43)
Recycled blockboard	4072.71 (11.79)	808.58 (12.43)	6113.94 (9.88)	1316.00 (16.97)
Brown rot	2199.29 (8.19)	795.30 (10.15)	2709.88 (11.42)	568.54 (7.55)
White rot	2992.55 (12.10)	604.36 (12.99)	5422.54 (13.50)	922.84 (14.98)

Note: Value at parenthesis is coefficient of variance.



(a)



(b)

Fig. 3 Force-displacement diagram of stress loading in the angular plane – average value (a) wooden dowel joint, (b) confirmat joint.

Tab. 3 One-way analysis of variance for the load-carrying capacity under compression bending and joint stiffness.

Effect	DOF	Stiffness ($N\cdot mm^{-1}$)	Maximum load (N)	Stiffness ($N\cdot mm^{-1}$)	Maximum load (N)
		F	p	F	p
Intercept	1	5158	0.0000	8657.61	0.0000
Material	5	142.75	0.0000	263.37	0.0000
Direction	1	644.13	0.0000	545.71	0.0000
Material * Direction	5	178.05	0.0000	47.84	0.0000

Note: DOF – Degree of freedom, F – Test value, p – Probability.

Tab. 3 shows that at the significance level of 0.05, all investigated factors, *i.e.*, type of fastener (p=0.000) and type of material or density (p=0.000), as well as their interaction (p=0.000), were significant for both the load capacity and stiffness of corner joints. It means that a change in any of the investigated factors will result in a change in the load capacity or the stiffness of the corner joint, respectively.

Withdrawal resistance and stiffness of the screw

The average values of the mechanical properties, the withdrawal resistance F (N) and withdrawal stiffness T ($N\cdot mm^{-1}$) for screws ø3.5 × 30 mm loaded by axial force embedded in the tested materials at their surface and edge are given in Tab. 4.

Tab. 4 Mechanical properties of axially loaded screws ø3.5 × 30 mm embedded in the tested materials.

PBs type:	Withdrawal from the surface		Withdrawal from the edge	
	Withdrawal resistance (N)	Withdrawal stiffness ($N\cdot mm^{-1}$)	Withdrawal resistance (N)	Withdrawal stiffness ($N\cdot mm^{-1}$)
Commercial	863.59 (8.22)	349.64 (10.75)	625.06 (14.52)	381.66 (12.94)
Control	595.22 (7.40)	352.95 (13.40)	403.15 (4.39)	250.75 (18.01)
Recycled PB	379.17 (14.41)	210.23 (17.26)	273.02 (18.12)	214.09 (19.47)
Recycled blockboard	556.44 (9.45)	309.77 (21.40)	416.61 (8.13)	246.89 (11.36)
Brown rot	339.43 (11.28)	225.59 (14.41)	219.47 (17.87)	153.09 (40.41)
White rot	505.62 (6.96)	245.41 (13.54)	338.10 (19.42)	216.15 (27.42)

Note: Value at parenthesis is coefficient of variance.

Tab. 5 One-way analysis of variance for withdrawal stiffness and resistance of ø3.5 × 30 mm screws.

Effect	DOF	Sigma-restricted parameterization Effective hypothesis decomposition			
		Withdrawal stiffness ($N \cdot mm^{-1}$)		Withdrawal resistance (N)	
		F	p	F	P
Intercept	1	3834.86	0.0000	9096.13	0.0000
Material	5	38.41	0.0000	193.90	0.0000
Load Direction	1	16.29	0.0001	277.97	0.0000
Material * Load Direction	5	4.62	0.0007	4.36	0.0012

Note: DOF – Degree of freedom, F – Test value, p – Probability.

Following the one-way analysis of variance (Tab. 5), the effect of selected factors on the withdrawal resistance of the screw ø3.5 × 30 mm was determined. The effect of all factors, density of materials and load direction acting simultaneously was statistically significant at the 5% significance level (p=0.007) when evaluating withdrawal stiffness. The effect of all factors, density of materials and load direction acting simultaneously, was statistically significant at the 5% significance level (p=0.001) when evaluating withdrawal resistance.

Higher withdrawal resistance and withdrawal stiffness was achieved when the screw was embedded in the surface of the specimen (perpendicular to the plane of the plate). The highest values of withdrawal resistance were achieved by the screw embedded in the surface of PB from recycled blockboard at the level of 556.44 N, which is 25.13% higher than for edge embedding with a capacity of 416.61 N. Compared to commercial PB (863.59 N), the withdrawal resistance for PB from recycled blockboard is 35.56% lower for surface embedding and 33.34% lower for edge embedding. The smallest withdrawal resistance values were performed by the brown rot specimen. Compared to the commercial PB, the values for the surface were lower by 60.69% and for the edge were lower by 64.88%. The screw withdrawal stiffness was also the highest for the PB from recycled blockboard compared to other tested materials. Compared to commercial PB, the withdrawal stiffness of PB from recycled blockboard withdrawal resistance for this material was lower, with a difference of 11.40% for surface embedding and 35.31% for edge embedding.

Fig. 4 shows characteristic damage of a glued wooden dowel joint and Fig. 5 shows damage of a confirmat joint.

(a) **(b)**

Fig. 4 Failure modes in some of the studied cases – wooden dowel at:
(a) commercial PB and (b) PB with recycled particle board.

(a) **(b)**

Fig. 5 Failure modes in some of the studied cases – confirmat at: (a) commercial PB and (b) PB with recycled blockboard.

The lower quality of the recycled PB and lower-quality timber was also reflected in the extent of damage around the fastener. According to the work (Langová and Jočšák, 2018), the extent of the damage for ø5 × 50 mm confirmat for spruce and beech joints was 10 mm in diameter around the fastener header. This damage was up to 30 mm in diameter for commercial PB and MDF materials. In the case of the materials tested in this study, the damage was manifested through the entire width of the specimen (50 mm). For a glued ø6 × 30 mm wooden dowel, the material was visible to be torn out at a distance of 18 mm from the centre of the dowel. Although the difference in densities between commercial PB and boards made of recyclate or using lower quality timber was negligible, there was a visible difference in damage at the glued joints. In commercial PB, the dowel breaks, while in the tested specimens the material around the glued joint was torn out. For the confirmat designed for bonding PB when joining commercial PB, there was a bending of the confirmat, which was typical damage to the joint, in our tested specimens there was a breakage of a part of the structural board. This type of damage is related to the quality of bonding in the production of PB.

Discussion

The density values of the control PB were lower, which may be due to the production technology in laboratory conditions.

The measured and calculated load capacity values of corner joints PB made from recycled material and lower quality timber with commercial PB and solid timber can be compared. According to the work of Langová and Jočšák (2018), the assumption that the mechanical properties are influenced by the density of the material and the bolt dimension but also by the thickness of the material was confirmed. For comparison, the values of the strength properties of ø5 × 50 mm compression-loaded corner screwed joints were presented.

The highest load capacity values were achieved by the PB made from recycled blockboard 6113.94 N·mm, which is comparable to the load capacity of commercial MDF with 12 mm thickness, $\rho = 680\ kg{\cdot}m^{-3}$ (6890.00 N·mm). In the case of our recycled PB, the loading capacity was 3312.32 N·mm, which is comparable to that of commercial PB with 12 mm thickness (3600.00 N·mm) or to that of a joint made from spruce lumber with 12 mm thickness, $\rho = 392\ kg{\cdot}m^{-3}$ (4580 N·mm). According to the work of Antov *et al.* (2020), corner joint with ø7 × 50 mm confirmat made from eco-friendly boards, produced in the laboratory with a density of 720 $kg{\cdot}m^{-3}$ and 15% magnesium lignosulfonate gluing content, based on the dry fibres, achieved a loading capacity value of 6950 N·mm.

The effect of the diameter of the fastener and the density of the material to be bonded was also confirmed in the case of bonded joints. In our case, a joint of PB made from recycled blockboard (ρ = 649 kg·m^{-3}) with a glued wooden dowel ø6 × 30 mm achieved a loading capacity of 4072.71 N·mm. In the work of Antov *et al.* (2020) a joint made of eco-friendly boards (ρ = 726.5 kg·m^{-3}) with a glued wooden dowel ø 8 × 30 mm achieved a two times more loading capacity of 8020.00 N·mm. The highest stiffness values were achieved in the case of the PB made from recycled blockboard 1316.00 N·mm/°, which is comparable to the stiffness of commercial PB with 12 mm thickness (1279.50 N·mm/°) and 12 mm thick commercial MDF, ρ = 680 kg·m^{-3} (1805.01 N·mm/°). For both commercial materials, with 18 mm thickness, the joint stiffness was almost three times higher compared to the PB made from blockboard recyclate, which showed the best strength properties for both types of fasteners among the tested materials.

The axial screw withdrawal resistance is influenced by the density of the material. Higher values were achieved for screws stressed to pull perpendicularly from the surface of the specimen, which is also suitable from a practical point of view when attaching furniture fittings. In terms of the axial screw withdrawal resistance of ø3.5 × 30 mm screw, the best results were achieved by the PB made from recycled blockboard (556.44 N), which is almost 1.5 times less compared to commercial PB. Compared to spruce parallel to the grain in the tangential and radial directions (1117.00 N) and perpendicular to the grain (1034.00 N), it is 2 times less.

In the work of Pereira *et al.* (2018), panels reinforced fibers reached about 74% of the maximum strength achieved by MDF samples. Panels reinforced with pejibaye showed the worst mechanical performance. However, hybridization between pejibaye and fibers resulted in a performance improvement of approximately 50% in the maximum withdrawal load comparing with panels reinforced only with pejibaye fibers. The results of Yorur *et al.* (2020) indicated that the average direct screw withdrawal resistance ranged from 695 N to 2076 N for frontal test blocks, while for lateral in MDF it ranged from 79 N to 1634 N. For PB frontal test blocks, the average direct screw withdrawal resistance ranged from 474 N to 1646 N, while for lateral it ranged from 190 N to 1313 N. The results of Sackey *et al.* (2008) studies indicate that not only the content of fine particles, but also the ratio of all fractions with particle size strongly influences the efficiency and strength of the bond. In three-ply particleboards with a low target density, replacing 20% of the fines content of the total slurry with coarse particles increased the internal joint strength by 40% and the screw adhesion by 18%. Wronka and Kowaluk (2022) reported that the screw withdrawal resistance decreases with subsequent re-milling of the PB to produce the PB out of recovered particles. The progressive milling of the PB leads to achieving a fraction of the fine-size particles of growing bulk density, which influences the density profile of the panels produced, especially of the face zone. This local densification allows the surface soundness to be kept high, irrespective of the decrease in other mechanical parameters, such as internal bond and screw withdrawal resistance.

In the event of a decrease in forest resources, it is possible to produce PB from various raw lignocellulosic materials. Several studies have dealt with this area. Based on the findings of these studies, we can conclude that sources of agricultural raw materials such as cane stalk (Kord *et al.*, 2015) and lignocellulosic particles of raspberry Rubus idaeus L. (Kowaluk *et al.*, 2019) or rice husks (Kwon *et al.* 2013) meet the standard and in some cases PB had improved physical and mechanical properties, therefore, they are a suitable material for the production of PB.

CONCLUSION

- Comparing results for tested mechanical properties of this study with other works carried out under the same loading conditions and dimensions of the test bodies, it can be concluded that particleboard made from recycled materials and lower-quality timber achieves significantly lower strength properties compared to commercial PBs. These properties are evaluated through the mechanical resistance of the joints. Therefore, these materials find application in non-load-bearing elements of furniture structures. In the case of brown rot, the boards can be used as part of decorative interior elements.
- The influence of the proportion of recycled or reduced quality timber is reflected in the density of the material and subsequently in the strength properties of the joints, with the highest values achieved by the PB made from recycled blockboard. Based on the determined strength characteristics of the joints, producing structural boards by adding recyclate and not by adding timber of lower quality is recommended. When using a proportion of timber with brown and white rot, the strength properties of the joints show the lowest values.
- The extent of damage around the fastener highlights the need to reconsider the spacing of fasteners in structural joints but also the correct choice of fastener. A larger wooden dowel diameter is recommended for bonded joints.
- As the material is recommended for non-load-bearing or decorative interior elements, examining the adhesion of decorative veneers or foils is advisable.

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AUTHORS’ ADDRESSES

Ing. Viktória Satinová, PhD.
Ing. Zuzana Vidholdová, PhD.
Ing. Ján Iždinský, PhD.
Technical University in Zvolen
Faculty of Wood Sciences and Technology, Department of Wood Technologies

T. G. Masaryka 24
960 01 Zvolen
Slovak Republic
xsatinova@is.tuzvo.sk
zuzana.vidholdova@tuzvo.sk
jan.izdinsky@tuzvo.sk

Ing. Silvia Jánošíková
doc. Ing. Nadežda Langová, PhD.
Technical University in Zvolen
Faculty of Wood Sciences and Technology, Department of Furniture and Wood Products
T.G. Masaryka 24
960 01 Zvolen
Slovak Republic
xvanikova@is.tuzvo.sk
langova@tuzvo.sk