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RECYCLING RECOVERED WOOD-BASED MATERIALS. FLATNESS, MOR AND MOE OF PANELS MADE FROM RECOVERED WOODEN BASED MATERIALS

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Abstract

The objective of the research was to study the mechanical properties of recovered solid wood and wood-based materials, to create new panels made of strips of recovered oak and spruce wood, particleboards and blockboards and to study their mechanical properties, feasibility and use.

Flatness, MOR and MOE were determined for the solid wood and wood-based materials recovered from construction and demolition sites. Four types of experimental panels (PL1, PL2, PALL1 and PALL2) were manufactured from solid wood strips alternating with either particleboard or blockboard strips glued edge to edge. Some of their physical and mechanical properties were investigated. All new panels made from recovered materials fell within allowable limits specified in European standard requirements for panel flatness. Panels type PL2, PALL1 and PALL2 show better values for MoR and MoE parallel to the grain when compared to the respective values for the recovered wood-based materials of which they are made, but panels type PL1 show no change. Panels type PALL2 are preferable to panels type PALL1 due to better mechanical properties. Panels type PL1 and PL2 show no such differences in their structure. The results also show that these new panels can be used successfully in furniture production, provided panels type PL1, PL2 ad PALL1 do not bear loads perpendicular to the grain or receive reinforcing elements.

Key words: *recovered wood-based materials; new panel structures; flatness; MOR and MOE.*

INTRODUCTION

To ensure a stable supply for multiple purposes and to meet the growing demands, the efficiency of the use of wood and composite boards as resources may be enhanced and additional sources have to be identified (Höglmeier et al. 2013). Wood and wood-based materials recovered from construction and demolition sites could be promising additional sources for furniture manufacturing.

The construction and demolition (C&D) waste can be defined as waste material produced in the process of construction, renovation or demolition of structures (Statistics Canada 2000 in Yeheyis et al. 2012). The C&D is often a significant component, representing 20–30 % and sometimes more than 50% of the total municipal solid waste. C&D waste is composed mainly of wood products, asphalt, drywall, concrete and masonry (Yeheyis et al. 2012). The main C&D waste management systems include waste avoidance and minimisation through recycling/reusing, waste to energy options (where possible) and safe disposal and discharge only as a last resort (Marchettini et al. 2007 in Yeheyis et al. 2012).

Earlier studies (Höglmeier et al. 2013) had revealed a considerable amount of recovered wood from the building sector available in conditions which allow a high-quality material to be recovered and reused: 45% of the recovered wood from building deconstruction is potentially suitable for use as raw material for particle-or fibreboard production and 26% would even be applicable in a re-use scenario, thereby adding an additional step to a possible cascading of recovered wood and thus increasing the time span of carbon storage in wood products in order to delay its contribution to the greenhouse effect. 27% of the recovered wood may be utilized for high-quality secondary applications (Höglmeier et al. 2013).

Reuse and recycling of wood as a material can be considered as downcycling (except reuse in a very strict way): diameters, size of wooden material pieces decrease while “unwanted” contaminants increase with each processing step. The more often wood is reprocessed, the more limited its potential applications. Original properties can only be restored with the investment of non-renewable energy and material (Werner 2005). Therefore, it is important to recycle wood and wood-based materials, when possible, with minimal energy consumption (Papanek 1995, Vezzoli and Manzini 2008). In order to produce quality products made from recovered wood-based materials, the mechanical and technological properties of these new materials have to be appropriate for meeting present quality requirements.

OBJECTIVES

The objectives of the research were to study the mechanical properties of recovered oak and spruce wood, melamine faced particleboards and blockboards, to design new panel structures manufactured from strips of the recovered materials, to investigate the mechanical properties of the new panels - flatness, MOR and MOE, and decide if they are suitable for furniture. The research was carried on as part of the doctoral thesis “Furniture eco-design with recovered wood-based materials”.

MATERIALS AND METHODS

Due to the economic importance of some wood based materials, in this study the following wooden materials originating from demolition were selected for recycling: recovered particleboard (PB), blockboard, solid oak and spruce wood. The PB and blockboard had been recovered from office furniture continuously used for several decades (Table 1). Oak and spruce wood had been used as construction elements (beams and frames).

The original recovered wooden materials, PB, blockboard and oak wood recovered from demolition had been tested for mechanical and technological properties before studying the flatness, MOR and MOE of the panels made from these materials. The tests had included density, moisture content, shrinkage and swelling coefficients, MOR and MOE, withdrawal capacity of fasteners and compression parallel to the grain. Previous studies encourage the use of old oak wood recovered from construction and demolition, due to its good mechanical properties and to the assumed ways of identifying and eliminating areas of degradation or by antifungal treating. A good perspective had been opened for its use in association with recycled wood-based materials like PB and blockboard. Studies made by Thaler and Humar (2013) also confirmed that the mechanical and technological properties of recovered solid wood enable it to be recycled into new products.

Table 1.

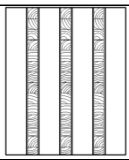
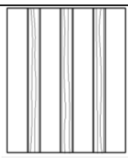
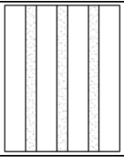
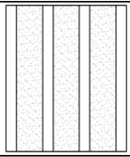
Properties of the recovered wood-based materials

Type of material	Recovered PB	Recovered Blockboard	Recovered oak	Recovered spruce
Dating	1980-1982	1965-1970	1830-1831	1971-1972
Origin	Manufactured in Romania between 1980-1982, office furniture discarded 2011	Manufactured in Romania between 1965-1970, office furniture discarded 2012	Recovered from a house in Homorod village, Harghita County, Transylvania, built 1831, renovated 1878 and demolished 2000	Recovered from construction elements (additional structures, 1972), Transilvania University (building H), dismantled 2012
Original thickness [mm]	18.70	20.39	26	34 and 44
Density [Kg/m^3]	789	470	644	345
Moisture content [%]	8.13	7.89	9.84	8.27

Four types of experimental panels (PL1, PL2, PALL1 and PALL2) were manufactured from glued solid wood strips (with the section of 35x20mm) in alternation with PB and blockboard strips (20x20mm blockboard and 18x20mm PB) joined edge to edge (Fig. 1). The structure of the experimental panels is presented in Table 1.

Table 1.

Structure ad physical properties of the experimental panels

Panel Type	PL1	PL2	PALL1	PALL2
				
Structure	Strips of solid spruce (35x20 mm) in combination with strips of blockboard cut perpendicular to the outer layer(20x20 mm)	Solid spruce strips (35x20 mm) in combination with strips of blockboard cut parallel to the outer layer (20x20 mm)	Solid oak strips (35x20 mm) in combination with particleboard (18x20 mm)	Particleboard strips (35x16 mm) in combination with solid oak strips (20x16 mm)
Density, [*kg/m*^{3}]	435.84	442.52	753.79	731.15
Moisture content, [%]	8.28	8.07	9.24	7.97

The manufacturing process of the new panels comprises: **1**. Sorting and preparation of strips to form the panels. The preparation includes: removal of metallic components or various dowels and cleaning; **2.** Sanding the recovered melamine faced PB and blockboard in order to remove the lacquer and melamine layers; **3**. Straightening and planing of spruce and oak timber to obtain the required thickness; **4**. Cutting strips of recovered PB, blockboard, spruce and oak timber; the resulting strips were 35x23mm for oak and spruce wood, 23x18mm for PB and 23x20mm for blockboard; **5**. Glueing the strips edge with a non-toxic polyurethane adhesive JOWAT Uni PUR 687.22 for solid wood and JOWAT Multi PUR 685.44 for PB and blockboard, either manually or mechanically; specific consumption for both polyurethane adhesives was 280g/m2; **6**. Assembling the strips to form the panels, by frontal and parallel clamping with specific pressure 0.02N/mm2, pressing time 3h at temperature 20±2°C and relative humidity of air φ=45±5%; **7.** Conditioning 8 hours at a T> 13°C and relative humidity of air 40-65 ± 5%; **8.** Calibration of panels with P80 grit size sanding; **9.** Panel sizing.

Density and moisture content of the panels were determined according to *EN 323:1993 Wood-based panels-Determination of density* and *EN 322:1993 Wood-based panels-Determination of moisture content*.

Table 2.

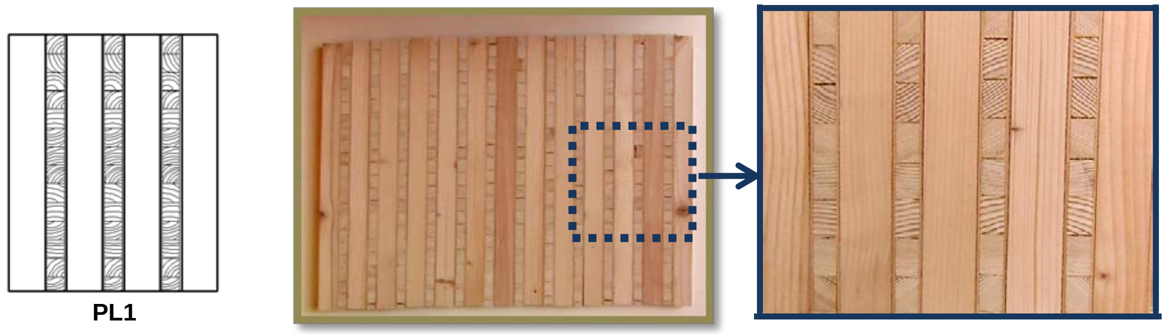
Type, structure and dimensions of the experimental panels tested for flatness

Type	Panel reference no.	Structure	Dimensions [mm]
PL1	PL1.2. PL1.3. PL1.4.	Solid spruce strips (35x20mm) with strips of blockboard cut perpendicular to the outer layer(20x20mm)	687 x 480 x 20 735 x 483 x 20 754 x 506 x 20
PL2	PL2.1. PL2.2. PL2.3. PL2.4.	Solid spruce strips (35x20mm) with strips of blockboard cut parallel to the outer layer (20x20mm)	594 x 506 x 20 685 x 505 x 20 640 x 488 x 20 755 x 485 x 20
PALL1	PALL1.1. PALL1.2. PALL1.4.	Solid oak strips (35x20mm) with PB (18x20mm)	715 x 485 x 20 710 x 497 x 20 720 x 504 x 20

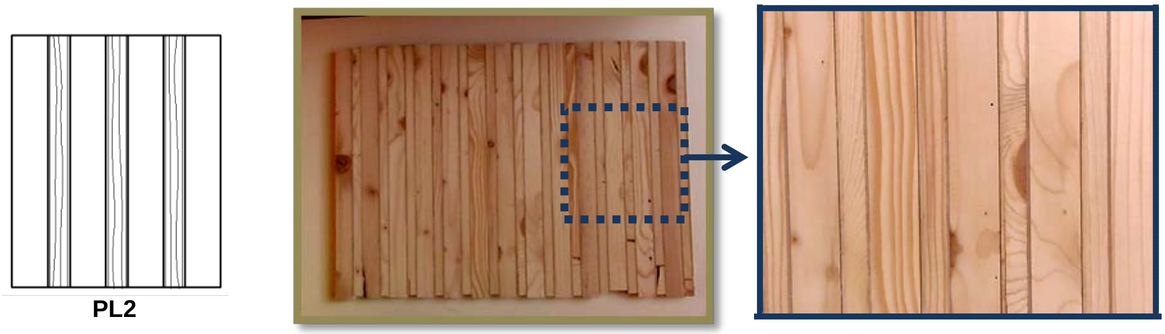
Flatness of the new panels

A total of 10 experimental panels made from recovered solid wood and wood-based materials were measured, 3 panels type PL1 and PALL1 and 4 panels type PL2, with different sizes (Table 2).

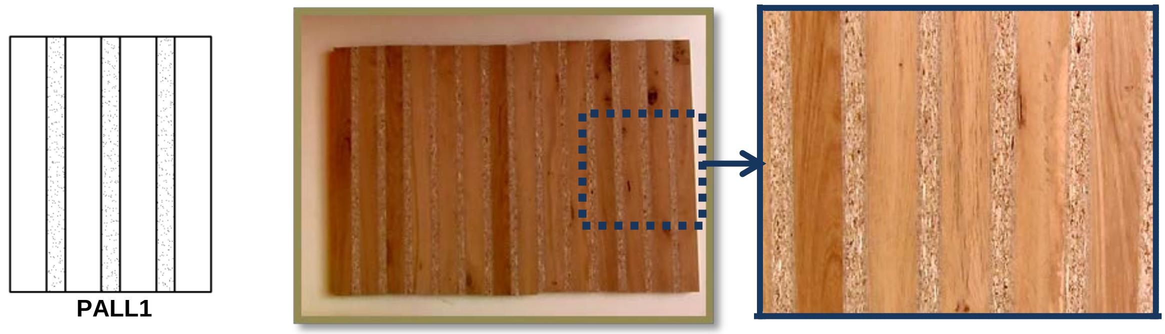
The flatness of the panels was measured according to EN 952:2002 by measuring the deflection of the panels in at least 5 points, 4 of which were positioned at 20mm from the edges and the fifth was situated in the centre of the panels.



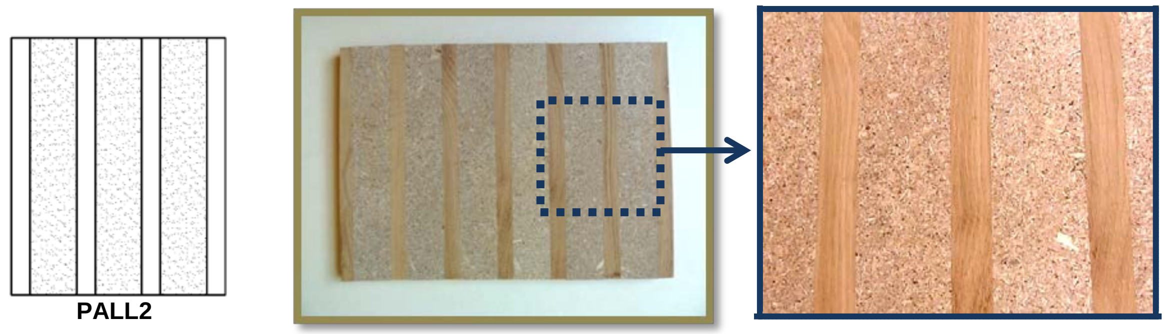
a.



b.



c.



d.

Fig. 1.
Structure and details of the new panels:
a – Panel PL1; b – Panel PL2; c – Panel PALL1; d – Panel PALL2

The measurements were carried out with the OPTOdesQ Measurement Table machine; data was registered by PRUEFJOB MANAGER Soft. The test was conducted in the Laboratory of Testing Wood Processing Precision according to European Regulations, at the Faculty of Wood Engineering.

MoR and MoE of the new panels

MoE and MoR were determined according to EN 310: 1993 *Wood-based panels — Determination of modulus of elasticity in bending and of bending strength* (Table 3).

From each panel type 6 samples of 450x50x20mm (370x50x16 for panels type PALL2) were cut parallel to the grain and 6 samples perpendicular to the grain (Fig. 2). The samples were cut avoiding all macroscopically visible defects with a symmetrical cross-sectional area, with the weakest material in the middle, using a Festool CS 75 Preciso circular saw and a Festool 488289 circular blade, resulting a total of 48 test pieces. The dimensions of the test samples were measured with Holzmann digital callipers 150mm capacity or 300mm capacity and checked with a 25mm ±0μm setting rod.

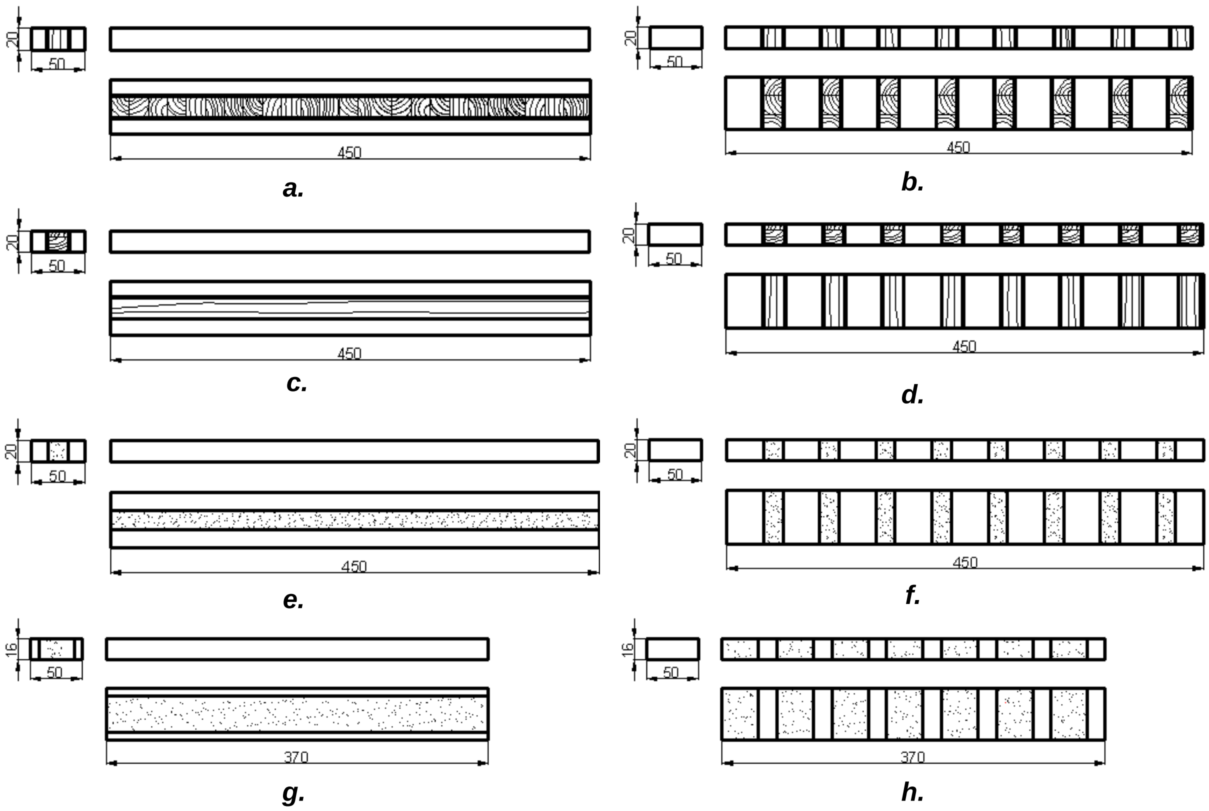


Fig. 2.
Shape and dimensions of the test pieces:
a – Panel PL1 with length parallel to the grain; b – Panel PL1 with length perpendicular to the grain; c – Panel PL2 with length parallel to the grain; d – Panel PL2 with length perpendicular to the grain; e – Panel PALL1 with length parallel to the grain; f – Panel PALL1 with length perpendicular to the grain; g – Panel PALL2 with length parallel to the grain; h – Panel PALL2 with length perpendicular to the grain

The test was developed in the Laboratory for Testing & Research of Wood and Wood-based Materials, where the IMAL Model IBX600 Universal Test Machine was used. The maximum load was recorded with an accuracy of 1% of the measured value. The deflection in the middle of the test piece (below the loading head) was measured with an accuracy of 0,1mm and plot these values against the corresponding loads measured to an accuracy of 1% of the measured value.

The experimental data was statistically processed according to ISO 2602–2:1981, by calculating the statistical mean $\bar{x}$, the standard deviation S and the lower limit of the confidence interval $L^{q}_{5\%}$, which eliminates eventual errors.

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pp. 173-180

Table 3

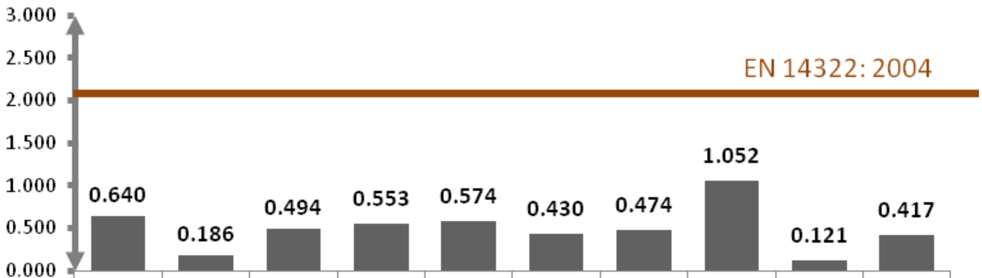
Dimension and number of test pieces and mechanical testing methods

Test	Size of the test pieces, [mm]	Method	Formula		No. of test pieces
Density	50±0,5 x 50±0,5 x t±0,5	EN 323:1993	$\rho=m/(b_1xb_2xt)x10^6$	[*kg/m^3*]	5
Moisture content	50±0,5 x 50±0,5 x t±0,5	EN 322:1993	$H=(m_h-m_0)/m_0 100$	[%]	5
Flatness	Free dimensions	EN 952:2002		[mm/m]	10
MoR ǁ	450±1 x 20±0,5 x 20±0,5 370±1 x 20±0,5 x 16±0,5	EN 310:1993	$MoR=3P_{max}l/(2bt^2)$	[N/mm^2]	6
MoR ⊥					6
MoE ǁ			$MoE=l^3(F_2-F_1)/[4bt^3(a_2-a_1)]$		6
MoE ⊥					6

Where: *ρ* is the density; *m* is the mass of the test pieces in g; H is the moisture content, m_H is the initial mass of the test piece, in **g;** m_o is the mass of the test piece after drying, in g. *l* is the distance between the centres of the supports, in millimetres; *b* is the width of the test piece, in millimetres; *t* is the thickness of the test piece, in millimetres; *F*2 – *F*1 is the increment of load on the straight line portion of the load deflection curve, in N. *F*1 shall be approximately 10 % and *F*2 shall be approximately 40 % of the maximum load; *a*2 – *a*1 is the increment of deflection at the mid-length of the test piece (corresponding to *F*2 – *F*1), *P*max is the maximum load, in Newtons.

RESULTS AND DISCUSSIONS

Flatness values were best for panels type PALL1.2 and PL1.3, but in fact all studied panels fell within allowable limits specified in EN 14322: 2004 *Wood-based panels - Melamine faced boards for interior use-Definition*, *Requirements and classification* and STAS 770-88 *Wooden furniture. General conditions (Fig. 3)*.



	PL1.2.	PL1.3.	PL1.4.	PL2.1.	PL2.2.	PL2.3.	PL2.4.	PALL1.1	PALL1.2	PALL1.4
Flatness [mm/m]	0.640	0.186	0.494	0.553	0.574	0.430	0.474	1.052	0.121	0.417

Fig. 3.

Flatness of the tested panels in comparison with the allowable limit specified in EN 14322: 2004

The rupture of the test pieces occurred perpendicular to the surface along the wood chips in case of the panels containing PB and along the veneer and core fibers on the panel test pieces made of blockboard with their length parallel to the grain.

Values of MOR and MOE (Fig. 4 and 5) parallel to the grain for panels type PL2 were higher by 38% and 35% than those for panels type PL1 and for recovered blockboard, which the tested panel included. MOR and MOE (Fig. 4 and 5) perpendicular to the grain for panels type PL2 were higher by 27% than for panels type PL1 and values for both panels were 95% lower than those of recovered blockboard.

MOR and MOE parallel to the grain for panels type PALL1 are 203% and 171% higher than those of recovered PB. In the case of the panels type PALL1, MOR and MOE perpendicular on the grain are 98% less than values for the original recovered PB and 93-97% less than for PALL2. But MOR and MOE parallel to the grain for panels type PALL2 are lower by 97% than for panels PALL1 and higher than values for recovered and new PB.

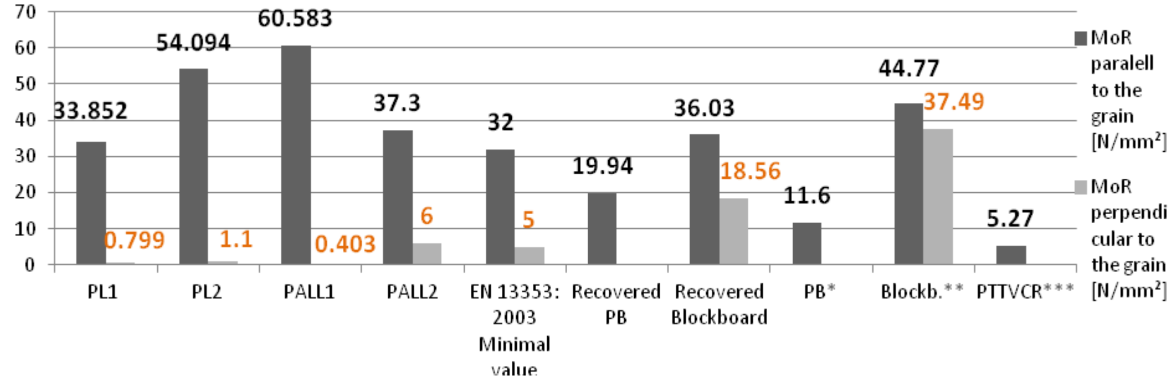


Fig. 4.
MOR parallel and perpendicular to the grain for panels type PL1, PL2, PALL1 and PALL2 in comparison with recovered PB and blockboard, minimal values for wood based panels according to EN 13353: 2003, new PB* (Clausen, Kartall and Muehl, 2000), new blockboard** (Laufenberg, Ayrilmis and White, 2006), panels made of branchwood *** (Olărescu, 2009)

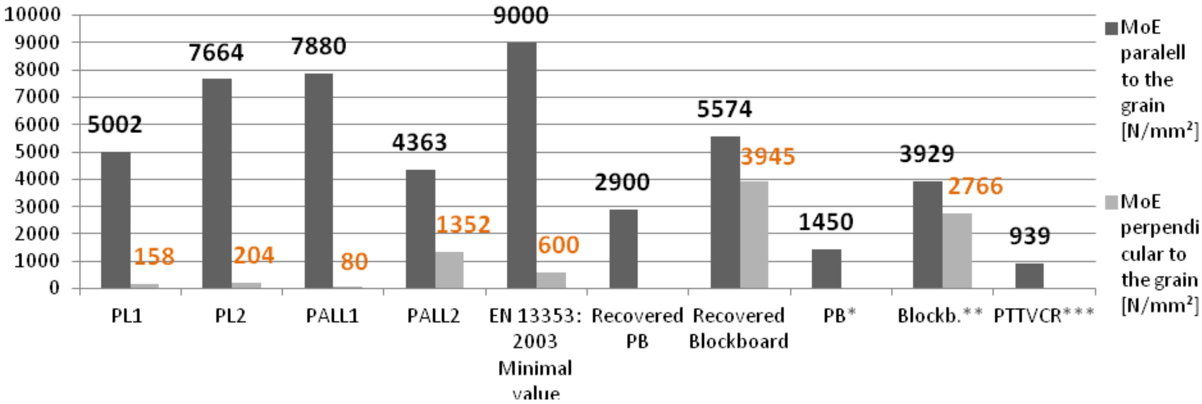


Fig. 5.
MOE parallel and perpendicular to the grain for panels type PL1, PL2, PALL1 and PALL2 in comparison with recovered PB and blockboard, minimal values for wood based panels according to EN 13353: 2003, new PB* (Clausen, Kartall and Muehl, 2000), new blockboard** (Laufenberg, Ayrilmis and White, 2006), panels made of branchwood *** (Olărescu, 2009)

CONCLUSIONS

Panels type PL2, PALL1 and PALL2 showed better MOR and MOE parallel to the grain than those of the recovered wood-based materials of which they are manufactured. Panels PL1 showed no significant improvement when compared to the respective recovered components materials.

The structure of panels type PALL2 is preferable to the structure of panels type PALL1 because panels type PALL2 have MOR and MOE perpendicular to the grain above the minimal required value according to *EN 13353:2004 Solid Wood Panels (SWP)-Requirements*. Panels type PL1 and PL2 showed no such differences in their structure.

The values of flatness, MOE and MOR show that the new panels made from strips of solid wood joined to PB and blockboard can be used successfully in furniture production, but it is recommended that panels type PL1, PL2 and PALL1 should either not bear direct load perpendicular to the grain or receive reinforcing elements.

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