Chapter 4
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Selected Properties of Wood-Based Panels as a Function of Raw Material, Applied Treatment and Exposure Conditions

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ABSTRACT

Wood based-panels are products in which wood is present in the form of chips, strips, veneers, strands or fibres. They were originally developed to provide utility panel materials with uniform properties. These panels are versatile products with a wide variety of end uses due to the features they present. They have a long history of continuous optimization. However, there is still a long way to be fully developed, new panels are ongoing researched and produced. In this chapter selected properties of particleboards, oriented strand boards (OSB) and fibreboards (MDF) under different treatments and exposure conditions are approached. The findings of various studies presented in this work could have practical applications for a better capitalization of wood resource in furniture manufacturing and to obtain value-added products.

Keywords: Particleboards; medium density fibreboards; oriented strand boards; overlaid panels; mechanical properties.

1. INTRODUCTION

Wood-based panels are man-made products designed for specific quality or performance requirements.These products can be made in different thicknesses, grades, sizes, and may present different degrees of exposure durability. They can be found in diverse array of applications, from industrial scale to small home projects [1,2].

1.1 Wood Based-Panels General Aspects

Wood based-panels are products in which wood is present in the form of chips, strips, veneers, strands or fibres. They were originally developed to provide utility

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panel materials with uniform properties. Four categories are usually recognised within this group of panel materials, as displayed in Table 1. These panels are versatile products with a wide variety of end uses due to the features they present [3]. These panels have a long history of continuous optimization. However, there is still a long way to be fully developed, new panels are ongoing researched and produced.

Table 1. Categories and featuers of wood-based panels

Category	Wood-based panels	Features
A	plywood, including blockboard and laminboard	- good strength/weight ratio; - good strength/cost ratio; - ease of working/finishing/fixing; - the range of sizes and thicknesses available; - the range of types and special products ; - good environmental credentials (made from a renewable raw material, recyclable, low life-cycle costs); - long and proven history of successful use;
B	particleboard, including wood particleboard (chipboard), flaxboard and cement-bonded particeboard	
C	oriented strand board (OSB)	
D	fibreboards, including medium density fibreboard (MDF).	

In this chapter selected properties of particleboards, oriented strand boards (OSB) and fibreboards (MDF) under different treatments and exposure conditions are approached.

1.2 Short Overview on Classification of Wood-Based Panels

Wood-based panels, also called wood composites, such as particleboards and medium density fiberboards (MDF), are major products for furniture manufacturing and interior design of living spaces. They can imitate the original wood structure and can provide comparable or even better mechanical properties.

Particleboards are obtained by hot pressing of wood particles of various sizes (wood flakes, chips, shavings, sawdust) or other lignocellulosic materials in particle form (flax, hemp, bagasse, straw), mixed with special binders [3]. The particle type determines the panel type (strand-OSB; flake-flakeboard; chip-chipboard; wafer-waferboard). The physical and mechanical features of particleboards depend both on the nature of wood and on the nature and characteristics of the adhesive, on the particle preparation and distribution in the board structure. The finer the particles, the more homogeneous and isotropic the boards are. Depending on the structure, there are homogeneous particleboards and layered (3 or 5- layered) particleboards. Besides standard boards other particleboard types and their technical classes are presented in Table 2 [3,4].

Table 2. Technical classes of particleboards and OSB

Type of particleboard/grade	Description
Standard particleboards-seven grades EN 312: 2010 [5] P1: general purpose boards for use in dry conditions P2: boards for interior fitments (furniture) for use in dry conditions P3: non load-bearing boards for use in humid conditions P4: load-bearing boards for use in dry conditions P5:load-bearing boards for use in humid conditions P6: heavy duty load-bearing boards for use in dry conditions P7: heavy duty load-bearing boards for use in humid conditions.	Wood chips are prepared in a mechanical chipper from coniferous softwoods (spruce, pine and fir) and hardwoods, such as birch. Softwoods are preferred to hardwoods because they tend to be easier to cut and the vessels present in hardwoods cause the chip to have a rough surface. Recycled resources may also be incorporated in particleboards. Synthetic resin systems are used, such as urea-formaldehyde (UF) or melamine-urea-formaldehyde (MUF), though phenol-formaldehyde (PF) and polymeric methylene di-isocyanate (PMDI) are used by a few manufacturers. Typical densities are 600 kg/m^3 to 680 kg/m^3. The special properties of particleboard have several advantages in a wide range of construction and furniture applications.
Oriented Strand Boards (OSB)-four grades, EN 300: 2006 [6] OSB/1 – General purpose boards, and boards for interior fitments (including furniture) for use in dry conditions OSB/2 – Load-bearing boards for use in dry conditions OSB/3 – Load-bearing boards for use in humid conditions OSB/4 – Heavy-duty load-bearing boards for use in humid conditions.	Consist of relatively long, wide and thin strands bonded together with a synthetic resin adhesive. Wood strands (spruce, pine, aspen) are cut tangentially from debarked logs which are held longitudinally against rotating knives. Three main adhesives are used in the production of OSB, such as phenol-formaldehyde (PF), isocyanates (MDI or PMDI) and melamine-urea-formaldehyde (MUF). OSB is usually composed of three layers, with the strands of the outer two layers aligned parallel to the long board edge and the production line. The strands in the core layer are often smaller and can be randomly oriented or at 90° angles to the strands of the faces. Typical densities are 600 kg/m^3 to 680 kg/m^3 Because of its lay-up and composition, OSB is primarily a panel for construction and is widely used for flooring, flat roof decking and wall sheathing, and also for packaging.
Waferboards	Are produced from plane, square, large particles using different binders. The layers of flakes are not oriented, which makes it easier to manufacture. They have a decorative aspect.
Flakeboards	Are produced by adhering thinly shaven pieces of wood together using resin before applying extreme pressure. The result is a synthetically constructed piece of wood that will not warp like natural cut wood. They have a compact and decorative surface. Usually are glued with PF resins and are used for outer wainscotings of wooden houses.

Fibreboards are obtained from wood fibres and fibre-boundles. They are classified according to their density and their surface characteristics as presented in Table 3 [7]. According to the surface characteristics, fibreboards can be melamine-faced, enamelled (with a shiny or opaque aspect, smooth or with imprinted drawings) or laquered. A special type of fibreboard is the acoustic board, produced in the natural colur of wood or covered with mechanical paste. There are two general technologies in the fibreboard manufacturing industry, such as the wet-process and the dry-process. For the former process the transport of the fibrous material and the mat formation are both carried out by means of water. The technique is widely used although it consumes large quantites of water and for this reason it raises finacial problems related to residual water. Another shortcoming of the process are the characteristcs of the obtained fibreboards: limited thickness, only one smooth surface, modest properties for humid conditions. The dry-process uses air to transport the fibres and form the mat. This technique is more ecological but it requires more complex equipment. MDF boards are produced exclusively by the dry-process. In this case a similar quantity of resins is needed as with particleboards.

This way high board performances are obtained, such as: bending strength, reduced thickness swelling, smooth surfaces and wide range of thicknesses (1.8-40mm). MDF is composed of fine ligno-cellulosic fibres (wood or plant fibres), combined with a synthetic resin (UF, MUF or phenolic resins and PMDI) and joined together under heat and pressure to form panels. The European definition of MDF is provided by EN 316 [8]. Out of the MDF technical classes, the following are the main grades: General purpose, dry (MDF), General purpose, humid (MDF.H), Load-bearing, dry (MDF.LA), Load-bearing, humid (MDF.HLS). The minimum requirements for these panels are specified in EN 622-5 [9].

Table 3. Classification of Fibreboards

Fibreboards					
Type of process	**Wet-process**		**Dry-process**		
The product density determines the panel type					
Type of board and density, kg/m^3	Softboard (insulation) <400	Hardboard >800	Light MDF <500	High HDF >800	MDF 500-800

2. SELECTED PROPERTIES OF OVERLAID PANELS EXPOSED TO HIGH-HUMIDITY CONDITIONS

2.1 Considerations on Overlaid Panels

Particleboard and MDF are still preferred nowadays to solid wood in cabinetry applications mostly for their low cost and finishing properties in overlaying and coating [10-12]. To keep a balance between quality and low cost, manufacturers may use panels with either higher density or higher thickness, as well as high-quality resins. Wood-based composites are hygroscopic materials changing their properties as a function of humidity. During processing and service, such composites are exposed to various changes of temperature and relative humidity which directly affect panel properties, such as thickness, surface smoothness, thermal and mechanical properties as well as formaldehyde emissions [13-16]. Under such influences the panel balance is disturbed and deviations from its initial flatness may appear affecting the overall performance of the final product [10,17]. Laminated and overlaid particleboard and MDF panels are commonly used in the furniture industry because they provide durable and decorative surfaces [18,19]. Resin impregnated decorative papers are used to produce both low-pressure laminates (LPL) and high-pressure laminates (HPL). Heat and pressure activate the resin in the impregnated paper creating a cross-linked bond with the substrate [10,20,21]. These light weight papers have a weight between 40 and 150 g/m^2 and can be manufactured from cellulosic or polymer-based synthetic papers [22]. A low-pressure melamine (LPM) paper is obtained by impregnation with the thermoset resin, typically melamine which is thermally fused to a substrate, such as particleboard and MDF to form melamine boards, but it does not have any kraft paper core as those found in HPL [20,21].

Decorative panels present a low impact resistance as a drawback but have some other key benefits such as low cost, readiness for use, easy maintenance, and availability in a variety of colors and finishes, along with a range of thicknesses to suit residential and commercial applications [23-26]. It was found that these impregnated papers retard the release of formaldehyde, reduce the absorption of humidity, and have improved abrasion and weathering resistance [27,28].

The surface quality of laminated panels is determined by the size of the wood particles or fibers on the surface layer. The so-called telegraphic effect is due to the roughness of the substrate penetrating through the overlay. Low humidity conditions do not affect any properties of these panels, but under exposure to high humidity, the surface roughness of these panels will be deteriorated [12,15]. A proper control of the temperature and relative humidity (RH) in a house is healthy for both the inhabitants and the furniture within. Therefore, it is important to quantify the effect of changes in RH over a period of time on the properties of laminated panels to have a better understanding of their behavior during their service life and use. There is a great potential for furniture production in Romania, including that of laminated furniture which is supported by residential construction works [29].

In this section the surface roughness and hardness of laminated wood-based panels exposed to 65% and 95%RH levels are evaluated. The findings of this study can be useful to enhance the manufacturing and service life of these overlaid products.

2.2 Materials and Methods

The experiments were carried out on commercially manufactured MDF and particleboards (PB) in Romania. To consider diverse products present in the market, the particleboard samples were supplied by two different companies.

Most of the PB and MDF are manufactured using formaldehyde-based adhesives, namely urea-formaldehyde and phenol-formaldehyde, which have low cost and provide panels with excellent physical and mechanical properties [30]. A total of 40 samples were cut in the dimensions of 95 × 95 mm. The samples were divided in four groups. Some samples were subjected to overlaying with melamine-impregnated paper. The overlaid and raw (non-overlaid) samples were exposed to humid conditions at a relative humidity of 95% for one and two weeks (Table 4). Control samples for each type of product were also tested in the established exposure conditions. Prior to any tests, all samples were conditioned for a week in a room having a temperature of 20 °C and a relative humidity of 65%. The density of the samples was calculated by measuring the dimensions and weight at accuracy levels of 0.01 mm and 0.01 g, respectively. Table 4 displays the characteristics of the composite samples and the experimental schedule. The Minitab 17.3.1 software was used to process all data and to compile the graphical representations as interval plots of the parameters under study at 95% confidence interval (CI) for the mean values. In this study, the status of the samples before exposure refers to their status when kept at room conditions at a temperature of 20 °C and a relative humidity of 65%.

2.3 Overlaying and Humidity Exposure of the Samples

A total of 20 samples, 10 for each type were overlaid with melamine-based decorative paper weighing 120 g/m^2. The decorative paper was applied on both surfaces of the sample and compressed using a pressure of 2.1 MPa at a temperature of 165 °C for 75 s by employing a laboratory Carver press. Eight overlaid and raw samples from each category and type of composite panels were placed in a chamber at a relative humidity of 95% and were kept there for one and two weeks, respectively. Two samples from each category were kept as control samples at room conditions at a temperature of 20 °C and a relative humidity of 65%.

2.4 Surface Roughness of the Samples

The surface roughness of all samples was determined before and after their exposure to humid conditions. According to ISO 4287 two roughness parameters, namely average roughness (*Ra*) and mean peak-to-valley height (*Rz*) were calculated from digital information acquired from the surface of each sample [32]. A portable surface roughness tester of SRT 6200 type equipped with a skid diamond stylus of 10 µm radius and 90° tip angle was employed for roughness measurements as illustrated in Table 4. Eight measurements, four on each side of each sample, were taken at a constant speed of 1 mm/s over a 15 mm tracing length. The cut-off length for the test was about 2.5 mm. The calibration of the profilometer was checked every 50 measurements using a standard reference plate with a *Ra* value of about 1.75 µm. The results of roughness measurements of the samples and their mass change rates as a function of the exposure conditions are presented in Tables 5 and 6, respectively. The particleboard samples were supplied by two different companies and therefore some differences in the roughness values of the samples before their exposure to humidity were recorded.

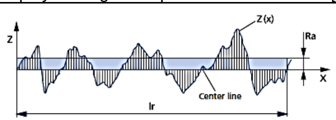
Table 4. Experimental Design [31]

Type of Panel	Particleboard (PB)		Medium Density Fiberboard (MDF)	
	Thickness, mm	Density, kg/m^3	Thickness, mm	Density, kg/m^3
	16	780	5	836
Number	20		20	
Dimensions	95 x 95 mm		95 x 95 mm	
Category and Number of Samples	Raw-10	Overlaid-10	Raw-10	Overlaid-10
	Note: Samples were set in three groups per category as displayed below:			
	control -2	exposed for 1 week-4		exposed for 2 weeks-4
Property to evaluate	Roughness of the samples		Janka Hardness of the samples	
Equipment	 Roughness tester of SRT 6200 type		 Comten Universal Testing Machine	
Overlaid and raw samples before and after testing				

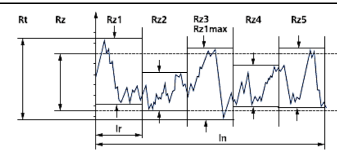
Table 5. Average values of surface roughness of the samples before and after exposure to humidity conditions [31]

Type of Panels			MDF		PB	
Exposure Time/ Roughness Parameter		**Category/ Status**	**Raw**	**Overlaid**	**Raw**	**Overlaid**
1 week	*Ra*, µm	before	6.48 (0.7) *	0.32 (0.11)	8.64 (1.3)	0.30 (0.14)
		exposed	6.75 (0.7)	0.31 (0.11)	8.75 (1.3)	0.32 (0.11)
	Rz, µm	before	18.34 (2.0)	0.93 (0.32)	24.46 (3.8)	0.85 (0.41)
		exposed	19.11 (2.09)	0.89 (0.31)	24.77 (3.77)	0.93 (0.31)
2 weeks	*Ra*, µm	before	6.62 (0.71)	0.36 (0.13)	7.17 (0.91)	0.31 (0.21)
		exposed	8.11 (0.98)	0.34 (0.11)	7.42 (1.12)	0.41 (0.37)
	Rz, µm	before	18.74 (2.02)	1.03 (0.37)	20.31 (2.58)	0.91 (0.62)
		exposed	22.98 (2.77)	0.97 (0.31)	20.98 (3.18)	1.18 (1.06)

Display of roughness parameters ISO 4287 [32]



R_a - the arithmetic mean deviation



R_z - mean peak-to-valley height

* Numbers in parenthesis are standard deviation values.

Interval plots at 95% CI for the mean values of the roughness parameters for raw and overlaid samples are displayed in Figs. 1 and 2, and Figs. 3 and 4, respectively.

As expected, both roughness parameters of the raw surfaces increased as a result of exposure to humidity as can be observed in Figs. 1 and 2. However, very small changes in the roughness parameters were noticed after one week of exposure to 95%RH.

In the case of the raw MDF samples, two weeks of exposure to humidity affected significantly the roughness of the samples. Increases of the roughness parameters corresponding to 22.50% for *Ra* and 22.40% for *Rz* were noticed for the raw MDF samples after two weeks of exposure compared to irrelevant differences in roughness of about 3.48% and 3.29% obtained for raw PB.

In a previous study similar values were found in terms of surface quality of non-overlaid PB made of redcedar and exposed to different relative humidity levels for 10 days [12]. In this study, the *Ra* values of the samples varied from 8.24 to 10.99 µm when the humidity level increased from 60 to 95%RH.

In the case of the overlaid samples, little changes were recorded in terms of surface quality for both exposed and control samples compared to raw specimens, as shown in Figs. 3 and 4. Such difference could be due to the protective surface of the overlay against relative humidity.

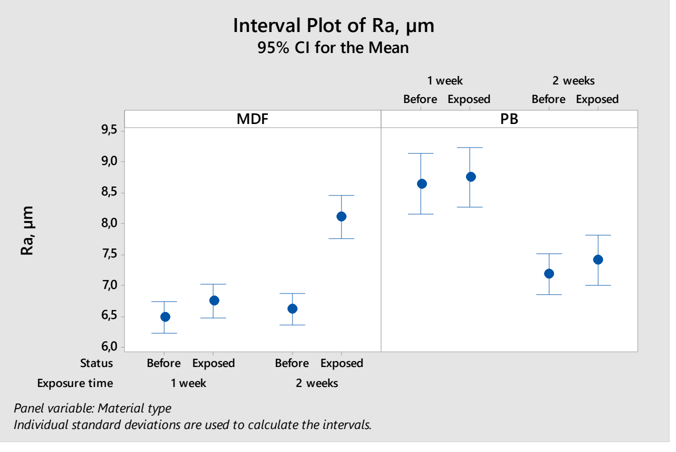


Fig. 1. Variation of the average roughness parameter (*Ra*) of the raw MDF and PB samples, before and after exposure to humidity conditions [31]

The roughness of the overlaid MDF samples did not change during humidity exposure. Very similar average values of *Ra* and *Rz* were determined at both exposure times. However, considering the median values of *Ra* and *Rz*, it appeared that the roughness of the surfaces slightly increased after two weeks of exposure, as indicated by the values of the two parameters, changing from 0.31 to 0.32 µm and from 0.88 to 0.90 µm, respectively. Hiziroglu and Suzuki [15] found that overlaid MDF made of sugi and hinoki wood showed a similar increase in the *Ra* values, from 0.61 to 1.25 µm, when the samples were exposed to 55% and 93%RH for three months.

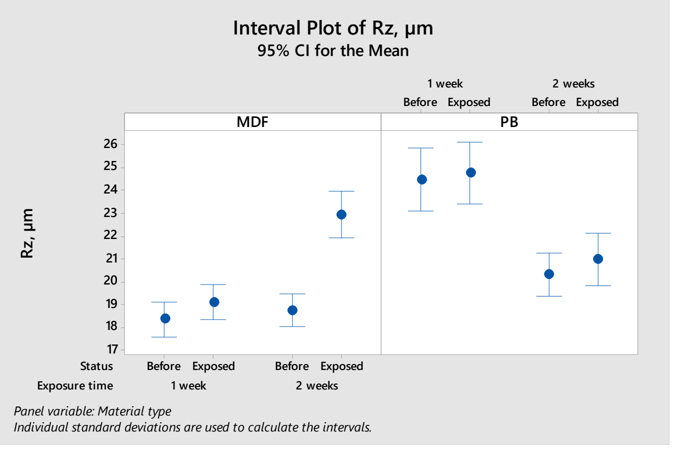


Fig. 2. Variation of the mean peak-to-valley height parameter (*Rz*) of the raw MDF and PB samples, before and after exposure to humidity conditions [31]

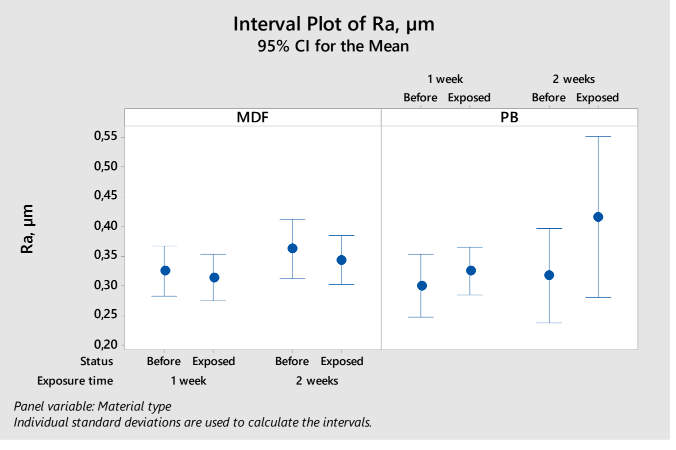


Fig. 3. Variation of the average roughness parameter (*Ra*) of the overlaid MDF and PB samples, before and after exposure to humidity conditions [31]

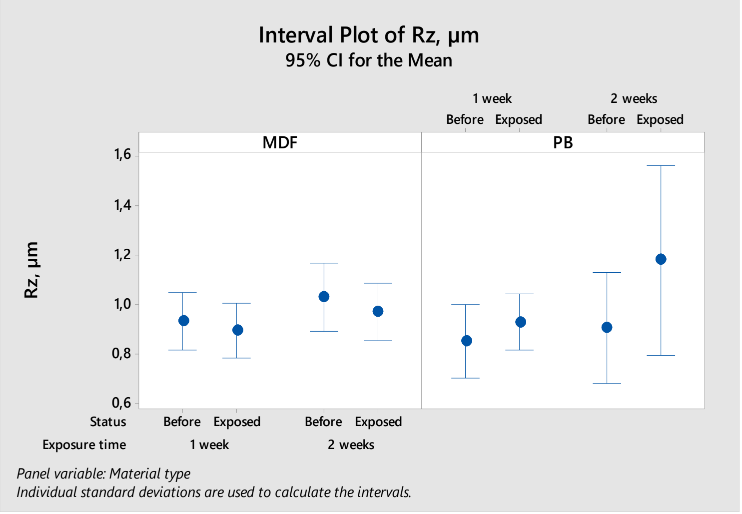


Fig. 4. Variation of the mean peak-to-valley height parameter (*Rz*) of the overlaid MDF and PB samples, before and after exposure to humidity conditions [31]

The results showed that all the surface roughness values of overlaid PB increased after both exposures to a humid environment of 95%RH. However, one week of exposure produced little change of the surface quality of these panels, and *Ra* and *Rz* increased by 6.6% and 9.4%, respectively. Two weeks of exposure influenced much more the roughness results, as shown by *Ra* and *Rz* increase of 32.2% and 29.6%, respectively. Hiziroglu and Suzuki [15] also found significant changes in the roughness values of *Ra*, varying from 0.68 to 1.5 µm for overlaid PB made of sugi and hinoki wood.

Table 6. Rate of mass change of the samples after exposure to humidity conditions [31]

Type of Panels/Category		**MDF**		**PB**	
Mass Change/Exposure Time		**Raw**	**Overlaid**	**Raw**	**Overlaid**
Mass change, %	After 1 week	5.98	3.17	4.02	2.25
	After 2 weeks	10.67	5.33	7.38	6.13

In regard to the mass change rate, an increase was found along as the exposure time to humidity increased for all four categories of samples (Table 6). As expected, the mass change rate was higher for the raw samples compared to the overlaid samples at the same time of exposure to humidity. PB panels were more resistant to mass change compared to MDF samples. The raw MDF samples exposed to humidity for two weeks were characterized by the largest mass change rate corresponding about 10.67%.

2.5 Hardness of the Samples

A Comten Universal Testing Machine was used to measure the Janka hardness. Four hardness measurements, two on each side of each sample, were randomly taken from raw and overlaid PB samples only before and after the exposure to humidity. The hardeness of MDF samples could not be determined because of their thickness. A steel sphere with a diameter of about 11.2 mm was half-embedded onto the sample surfaces as previously illustrated in Table 4.

The average values of the surface hardness of the raw and overlaid PB samples are also summarized in Table 7. Figs. 5 and 6 depict the graphical representations as interval plots at 95% CI for the mean values of hardness of the raw and overlaid PB samples, respectively.

Table 7. Average values of hardness of the particleboard samples before and after exposure to humidity conditions [31]

Type of Composite Panel			PB	
Exposure Hardness	**Time/Janka**	**Category/Status**	**Raw**	**Overlaid**
1 week	HJ, pounds	before	796.1 (76.30) *	931.3 (48.90)
		exposed	576.0 (61.40)	748.94 (25.91)
2 weeks	HJ, pounds	before	757.8 (67.70)	938.75 (36.12)
		exposed	562.0 (44.00)	653.56 (29.71)

** Numbers in parenthesis are standard deviation values.*

Exposure of the PB samples to high relative humidity will make them softer, and thus their hardness values are expected to be reduced. Therefore, the values of Janka hardness of all PB samples decreased after exposure to humidity. The hardness of the raw samples was reduced by 27.64% and 25.83% after one and two weeks of exposure, respectively. This result shows that the period of exposure had no influence on the hardness of the raw PB samples (Fig. 5). Initial average hardness values were found in the range of 796.12 to 757.75 pounds, and after one and two weeks of exposure, they were reduced to 576 and 562 pounds, respectively. The overlaid PB samples presented higher hardness values than the raw samples (Fig. 6). This could be attributed to the brittleness of the overlay paper. However, the hardness of overlaid PB was reduced by 19.58% and 30.38% after one and two weeks of exposure at 95%RH, respectively. Values in the same range were found for overlaid PB made of sugi and hinoki wood [15].

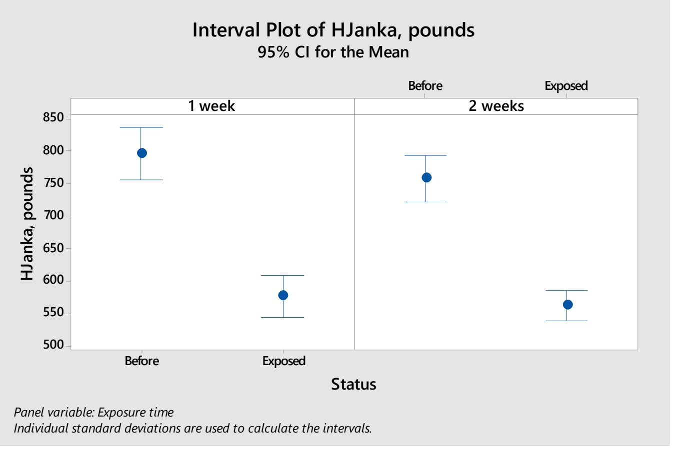


Fig. 5. Variation of the Janka hardness of the raw PB samples, before and after exposure to humidity conditions [31]

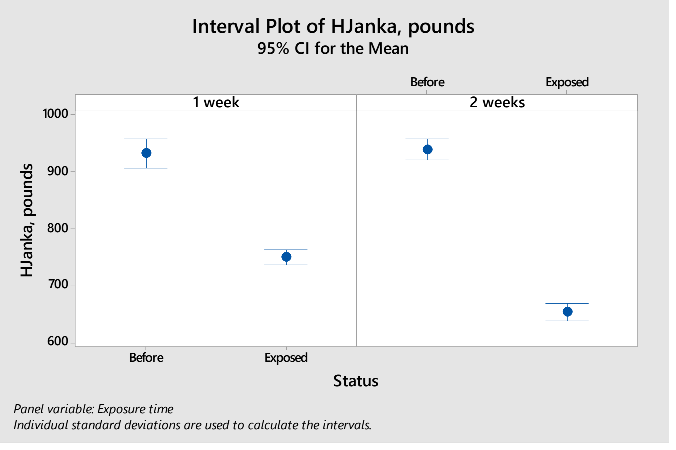


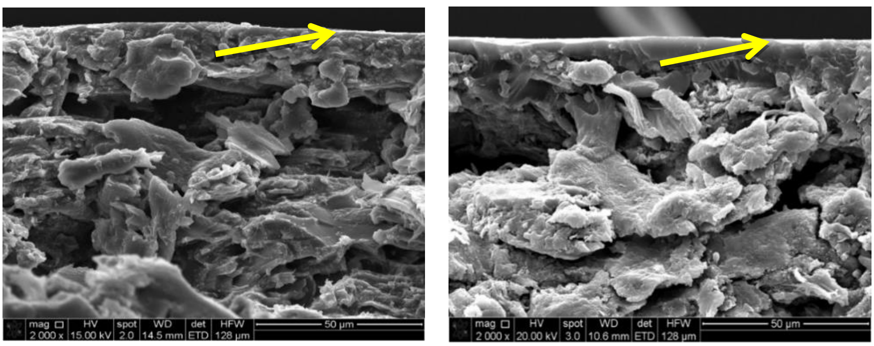
Fig. 6. Variation of the Janka hardness of the overlaid PB samples, before and after exposure to humidity conditions [31]

For overlaid PB made of redcedar and exposed to humidity levels of 60 and 95%, relatively low hardness values from about 440 to 375 pounds were found, different from the values found in this study. Such differences are due to the single-layer configuration of redcedar PB [15]. The results of this work are in accordance with those of the specialty literature regarding raw and overlaid MDF samples made of various species and exposed to different relative humidity levels [12,15]. The properties of the samples changed as a function of the relative humidity exposure, and this is related to the hygroscopic nature of wood and wood-based materials. Once humidity penetrated the samples, even for a short exposure time, the degradation of the samples was inevitable, resulting in changes of both physical characteristics and mechanical properties.

2.6 SEM Analysis of the Samples

The surface of the overlaid samples was examined by using SEM. Small samples with dimensions of 10 x 5 mm were cut from the control and exposed overlaid samples of MDF and PB. They were put under vacuum and coated with a thin film of gold using an ion sputtering device, before micrographs of the surfaces were taken with a SEM device of FEI Quanta600 F type.

Overlay papers were used to cover the composite samples. Upon exposure to high RH% level, a certain separation between the overlay and the substrate is expected to take place. Fig. 7 presents the SEM micrographs of the overlaid samples exposed for two weeks to 95%RH. The samples tested in this study did not show any delamination or separation either from the overlays or within the panels as a result of high humidity exposure.



(**a**) (**b**)

Fig. 7. SEM micrographs of exposed overlaid samples (melamine layer on the top): (a) exposed MDF; (b) exposed PB; (coloured arrows indicate the borderline between the overlay and substrate) [31]

2.7 Summary

In this study, the stylus method was used to determine the fluctuations of the surface quality of raw and overlaid composites. The surface quality of the raw and overlaid MDF and PB samples was influenced by increases in RH and exposure time. The raw MDF samples presented rougher surfaces after two weeks of exposure to humid conditions compared with the raw PB samples.

The surface quality of the overlaid MDF samples did not change much after exposure to humidity, while in the case of overlaid PB, some differences in terms of surface roughness were noticed. The mass change rate of the samples increased with the increase of the exposure time to a humid environment. The mass change rate was higher for the raw samples compared to the overlaid ones. However, the PB samples were more resistant to mass change than the MDF samples. The overlaid PB samples presented higher hardness values than the raw PB samples due to the brittleness of the overlay paper. The increase in RH adversely influenced the overall hardness values of the PB samples. No delamination or separation, either from the overlays or within the panels, as a result of high humidity exposure was found. The findings of this study can be applied to improve production techniques in furniture manufacturing and to enhance the use of overlaid composite panels.

3. SELECTED PROPERTIES OF WOOD-STRAW COMPOSITES AS A FUNCTION OF TREATMENT APPLIED TO PARTICLES AND ADHESIVE BEFORE PANELS MANUFACTURING

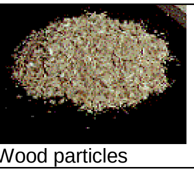
3.1 Considerations on Wood-Straw Composites

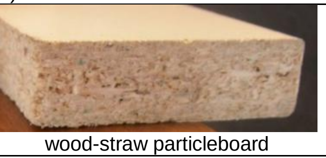
A great interest was shown the last decades to sustainable materials, approach that brings to light the use of various wastes, such as vegetable agro-waste to produce new materials. Therefore, the use of conventional wooden material for particleboards has shifted to the use of renewable resources. Even there have been few limitations connected to the lack of chemical knowledge and properties of these agro-materials, over the years wood chips have been substituted in particleboards production by particles obtained from annual plants, such as: wheat straw, rice straw, tea leaves, coconut chips, flax, hemp, kenaf, bamboo, bagasse, almond shell, corn peel, sunflower, sugar cane, and rapeseed, just to name a few [33-42]. Wheat straw is still one of the most abundant and cheap agro-waste materials in the world. The wheat straw is currently used in some limited applications: feed stuff, fertilizer, pulp industry, nano-materials, and for bio-ethanol also in pyrolysis, combustion and gasification [43]. Since 2010 straw has been used for the production of pellets and briquettes [44]. There are big amounts of wheat straw residues which are still burnt in the field causing significant environmental problems apart the loss of a valuable resource [45]. Wheat straw fiber and wood present different morphological features and mechanical properties, and in general they have a similar chemical composition, containing cellulose (33.5-40%), hemicellulose (21-26%), lignin (11-23%) and fewer contents of ash and protein [46]. The high content of silica (4.5-5.5%) in wheat straw leads to greater power consumption and also limits the service life of the crushing equipment. The fat-wax surface layer worsens wetting and gluing and it influences the adhesion between particles and represents a major obstacle for the particleboards production. The quality of bonding may be improved when removing the fat-wax layer by using some physical and chemical processes [47] or with glues having greater reactivity instead of urea formaldehyde (UF) glue [48-50]. Although it has some disadvantages, such as formaldehyde emissions it appeared that UF is still the most economical, due to its low cost and easy production, although it produces a low bonding with the straw particles [36]. But the bonding quality of wheat straw with UF resin may be improved by applying several treatments either to the raw material or to the adhesive itself [45,51]. In this section the effects of non-expensive treatments applied before the particleboard production are presented.

3.2 Materials and Methods

Wood particles from a particleboards producer and wheat straw resulted from local farms were used to produce experimental particleboards. Stems of wheat straw were cut, crushed and dried at 4% MC while wood chips were used as they were supplied and dried separately at same moisture content. A commercial UF resin with a solid content of 65% and ammonium chloride as a hardener were used for the particleboards manufacturing. The same pressing schedule of the wood-straw particleboards was applied, such as: the temperature of 170°C and the pressure of 2.2 MPa for 6 min. The panels (300 x 300 mm) were produced having the same target density of 650 kg/m^3. Panels with no treatment were manufactured as control panels. Three different treatments have been applied before the particleboard manufacturing to the adhesive and the raw material, as presented in Table 8. Prior to sampling the manufactured particleboards were kept in laboratory conditions at the temperature of 20ºC and 65% RH to reach the equilibrium moisture content. The modulus of rupture (MOR) and the tensile strength perpendicular to the surface (IB) were determined according to standards [52,53].

Table 8. Experimental design [54]

Raw material	 Wood particles	 Wheat straw	
Case and Treatment type	**Case A**	**Case B**	**Case C**
	UF resin modified by ethanol	Pre-treatment applied to straw by boiling	
Type of board and thickness	three-layered panel 16 mm	single-layer panel 19 mm	
Ratio between layers	20:60:20 (outer:inner:outer)	60% wood particles and 40% wheat straw	
Treatment	outer layers: wood particles + UF glue inner layer: wood and straw particles + modified UF glue (10 mass units of ethanol on 100 mass units of resin)	45 min- boiling in soapy solution of 20% concentration	45 min - boiling in water at 100°C



wood-straw particleboard

3.3 Effects of the treatment type on Mechanical Properties of Wood-Straw Composites

The results for the mechanical properties (MOR and IB) obtained for all the cases under study are displayed in Figs. 8 and 9.

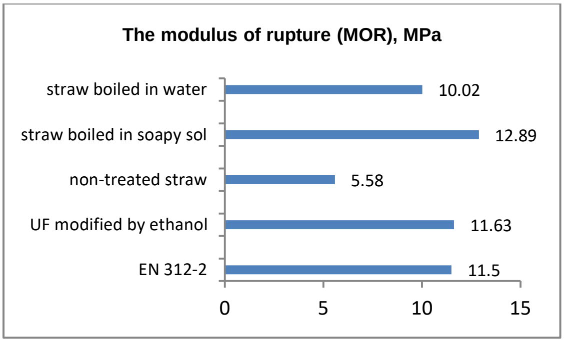


Fig. 8. Modulus of rupture of wood-straw particleboards as function of different treatment applied before manufacturing [54]

Case A - UF resin modified by ethanol

The results show that the wood-straw composites glued with modified UF resin by ethanol exhibited better properties when compared to those requested by standards specific to wood particleboards [55]. The ethanol contained by the glue was expected to dissolve the fat-wax layer of straw during the particleboards manufacturing. Therefore it was assumed that the hydrophobic effect of fat-wax layer on the adhesive interaction with particles decreases. During the pressing step the ethanol evaporates from the boards together with the moisture [56].

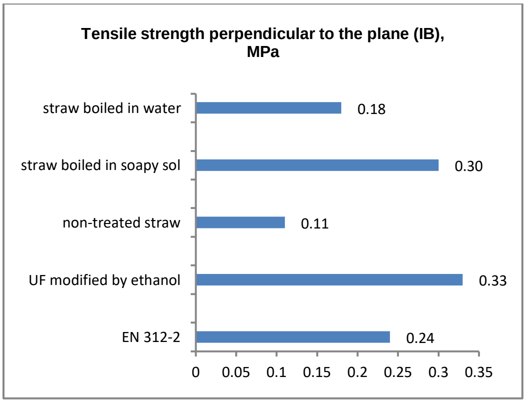


Fig. 9. Tensile strength perpendicular to the surface of wood-straw particleboards as function of different treatment applied before manufacturing [54]

Cases B and C - Pre-treatment applied to straw by boiling (soapy solution and water)

Both types of mixed particleboards made of wheat straw particles boiled in a soapy solution and water showed increased MOR and IB values when compared to that of control samples. The treatments applied to the raw material improved the properties of the samples and such result may be related to the dissolution of silica in the raw material when being exposed in such conditions. The reduction of silica in the straw particles may positively influence the bonding quality and the distribution of glue on the particles. When compared to the requirements of EN standards [55] it appeared that only the composite panels made of wheat straw particles pre-treated by boiling in soapy solution met them. Neither the control panels nor the boards made of boiled straw particles met those standard requirements. Therefore the pretreatment of straw particles with a soapy solution was found to be the most effective way to improve the mechanical properties of the wood-straw composites, such as the internal bond strength of the samples. Such result may be explained by the improved wettability of the raw material surface and consequently the subsequent improvement in adherence of UF resin and the hydroxyl groups of cellulose. The surface-active agents in the soapy solution contributed to the strong effect of the solution on the internal bonds in particleboards [45].

Similar results and conclusions from this work on the potential of such wood-agro-wastes particleboards were found by other authors in the field of composites [33,50].

3.4 Summary

Mechanical performance of wood-straw particleboards bonded with the UF modified glue by ethanol and that one of the particleboards manufactured from pre-treated straw raw material by boiling in soapy solution met the standard requirements specific to particleboards.

The results of this study show the potential of agro-wastes for the particleboards manufacturing.

4. SELECTED PROPERTIES OF OSB BOARDS AS A FUNCTION OF RAW MATERIAL

4.1 Considerations on OSB Boards

Oriented strand boards (OSB) are a substitute building material for plywood and particleboards [7]. These strand boards are produced to meet specific requirements related to thickness, density, size, texture, and mechanical strength. These specialty products are widely used for indoor and outdoor structural applications [57-60]. Canada and USA are the greatest OSB producers, with about 85% of the world production. OSB production has experienced continuing development in Europe due to growth in the residential building sector. A moderate increase was reported in 2017 in Germany, France, Spain, and Poland, but there is expected to be significant growth starting from 2019 both in Russia and Turkey, with expansion in Central and Eastern Europe (Romania and Ukraine) [61]. Approximately 28% growth in the OSB market was expected by 2020. Romania was the largest exporter of OSB (231 million Euro) in the EU between January and September 2017. The Egger and Kronospan manufacturing companies have made great investments in their production capacities for OSB boards [62].

The OSB manufacturers use water-resistant adhesives such as isocyanates (polymeric diphenyl methane diisocyanate (pMDI)), phenolic resins (phenol-formaldehyde (PF), melamine-urea-phenol formaldehyde (MUPF), or UF-melamine resins. Production lines in Europe use pMDI adhesives with additives in different percentages, especially in the core layer [4]. Compared with UF (62% solids) at 7% and 13%, pMDI (100% solids) at 4% and 6% results in superior board properties [63]. A mixed PF and pMDI resin system has been used to produce OSB boards made of various species, such as aspen, rubberwood, red maple, pine, bamboo, and mixtures of species [60,64-67]. Due to the high demand in the market, OSB manufacturers need to find suitable raw material for production. Strands for OSB boards presently are obtained from harvested wood only and not from recycled wood. In Eastern Europe, but also in Russia, Turkey, Latin America (Brazil and Chile), and Asia (China), investments are planned for the use of alternative resources such as bamboo, rice straw, or even fast-growing native species, which can double the capacities of existing production [68-71]. Past research on juvenile wood has shown its lower mechanical properties when compared to that of mature wood. This was found to be a major problem for using juvenile wood resource in the manufacture of wood composites due to their lower performance [72]. There are various studies on juvenile wood of *Pinus* spp. and its use for OSB manufacturing [73-76]. Other research studies have successfully associated the low cost of OSB manufacturing with the product performance when using small wood as raw material for OSB [77-79]. In Europe, almost all OSB production uses softwood species such as pine and spruce. The raw material for OSB production can also come from soft hardwood logs, as an alternative to resinous species. Studies on poplar wood, which is widely used in the EU, have been performed [80,81]. Beech, a high density species widely spread in Europe and mostly used for particleboards production or as firewood, was subsequently considered for OSB manufacturing [81]. Barnes [82] proposed an integrated model which showed that a high performance OSB product can be achieved by the control of process parameters, evaluation of raw material properties, its density and resin content, strands size, and their lay-up. An ideal OSB board was modelled by Sturzenbecher et al. [83]. The most important influencing parameters of OSB boards are: wood species elastic properties, their rate in the structure, strands orientation, and density profile [84]. The OSB performance depends on the mechanical properties of individual wood strands which can be connected to the macroscopic mechanical behavior of wood itself [75,84]. Such an approach is presented by Dixon et al. [85] who correlated the properties of bamboo with those of OSB made of bamboo strands. There is a specific need for monitoring the raw material stock before the manufacturing process in order to send it correctly and efficiently either to boards manufacturing or to bio-fuels [86].

The present study addresses fast-growing species in Romania, namely birch, willow, and poplar, which can replace softwoods or mixtures of wood species frequently used in the production of OSB boards. The experimental study focuses on some physico-mechanical properties of these wood species that influence the properties of OSB boards made 100% of strands from each individual wood species.

4.2 Materials and Methods

The raw material used for this study was provided by a local OSB manufacturer in Brasov, Romania. Thin logs of fast-growing species, such as birch (*Betula pendula* Roth.), willow (*Salix alba* L.), and poplar (*Populus tremula* L.) having a moisture content (MC) in the range of 60% to 116% were selected for the experiments. The logs of low grade complied with the conditions required for the OSB manufacturing, as presented in Table 9.

The wood material in the form of solid wood and strands was prepared at the company. Table 10 presents the selected physical-mechanical properties for solid wood and OSB boards. These tests were performed with a view to correlate the properties of wood species, especially the wood elastic properties, with the properties of OSB boards individually produced from each one of the species.

Table 9. Conditions for the Raw Material Imposed by the OSB Manufacturer [87]

Raw Material	Requested Conditions	Admissible Defects
Small-sized wood	- Minimum 10 cm diameter at the thin end; - Maximum 50 cm diameter at the thick end; - Length: 2 m; 2,5 m; 3 m; 3,5 m; 4 m; - Freshly cut at both ends; no clay, sand, ice, metals or other impurities; no soft rot; no major shape defects.	- A maximum curvature of 10 cm/m; cut knots along the log.

The wood samples were cut at standardized dimensions for each one of the properties listed in Table 10**.** Wood samples were dried in a regular oven at the temperature of 103 °C to get moisture content of about 10%. Prior to any determinations the samples were conditioned at relative air humidity (RH) of 65% at room temperature of 20 °C for one week.

The wood strands experimental method is presented in Table 11. The dimensions of the strands are different because the wood is not homogeneous. Wood strands were produced under industrial conditions with a high-capacity splitting machine with 52 knives. There can be differences in the structure and diameter of the logs. During the cutting, fracture planes can be radial or tangential, and the flakes can break more or less. After pressing all boards were cooled at room temperature for 48 h and prior to any test they were conditioned at 65%RH room temperature for one week to get 10% MC.

Table 10. Selected Properties of Wood Species and OSB Boards [87]

Type of Material	Properties / Standard Code / Equipment-Method / Number of Samples			
	Density (kg/m^3)	Bending Strength - MOR (N/mm^2)	Modulus of Elasticity in Bending – MOE (N/mm^2)	Internal Bond - IB (N/mm^2)
Solid wood	ISO 13061 [88]			-
	Gravimetric method	Universal machine IB 600 (IMAL, Globus Group, San Damaso, Italy)		-
	20	10	10	-
OSB	EN 323 [89]	EN 310 (major and minor axis) [52]		EN 319 [53]
	Gravimetric method	Universal machine IB 600		
	25	5+5	5+5	5

Table 11. Experimental design [87]

Dimensions of the strands			
Length, mm	Width, mm	Thickness, mm	
75-120	15-25	0.3-0.7	
Grades of the strands			
Large strands fior the face	Smaller strands for the core		
Drying of the strands at 10%MC			
Laboratory oven	Temperature, °C	Time, h	
	90	4	
The wood strands were blended with a **pMDI adhesive** (10%); no wax or additives were used			
Adhesive type	Viscosity at 25 °C, MPa	Density, g/cm^3	
LUPRANATE M20S	170-250	1.23	
Manually mat formation - the strands of core layer perpendicularly to the surface layers (1:2:1)			
About 1.6 kg of strands per each OSB board was used.			
Pressing schedule			
Laboratory press type	Temperature, °C	Specific pressure, MPa	Time, min
single-plate hydraulic	180	3	8
One OSB board per wood species – Total 3 boards			
OSB specifications			
OSB type	Density, kg/m^3	Dimensions, mm	
OSB/2 (load-bearing boards for use in dry conditions)	610	440 x 440 x 12	

The evaluation of physico-mechanical properties of solid wood and OSB boards were statistically analyzed using Minitab 17 software (Minitab LLC, State College, Pennsylvania, USA). The comparative analysis was applied based on probability plot with a confidence interval (CI) of 95%, boxplot charts, and interval plots in order to highlight the differences between the species under study.

4.3 Physical and Mechanical Properties- Evaluation of the Raw Material

To analyze the density as a physical property of solid wood the probability plot with a confidence interval (CI) of 95% for each one of the species was applied. The wood density values indicated higher values for birch when compared to poplar and willow based on the regression analysis with 95% CI (Fig. 10). The poplar and willow had similar density values. The minimum value in the case of birch density as 522 kg/m^3, while the maximum value was about 635 kg/m^3. Poplar and willow were graded as light wood species with densities between 310 kg/m^3 to 550 kg/m^3, while birch was considered harder than them and had density values in the range of 560 kg/m^3 to 650 kg/m^3 [90].

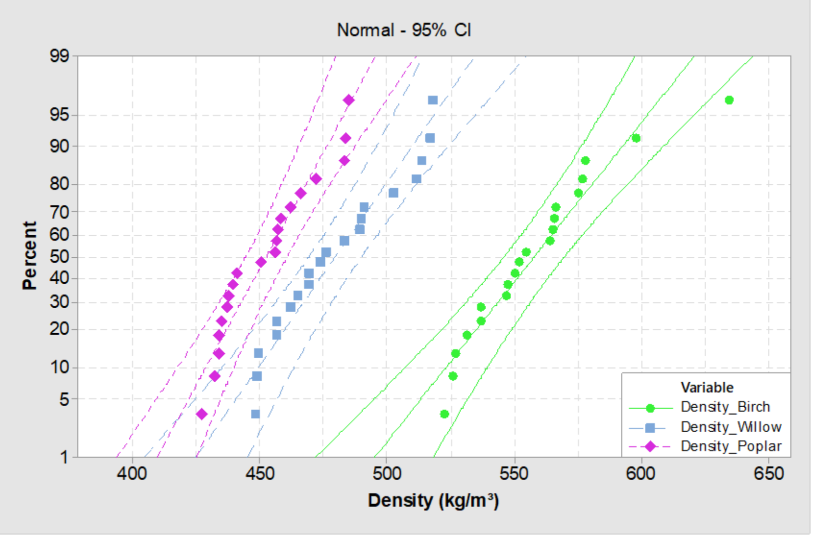


Fig. 10. Probability plot of density for analyzed wood species [87]

The mechanical properties of solid wood for the three species under study were modulus of rupture (MOR) and modulus of elasticity (MOE). To analyze the distributions of the measured data, the median value was considered. The box plot of properties for each species is plotted in Figs. 11 and 12. As expected, MOR and MOE values decreased gradually with the species density. Extreme low values for MOR were recorded for birch and willow (Fig.11). However, the birch species displayed a higher MOR (median = 78 N/mm²) than the other species. Birch presented a superior MOE value with a median of 6351.29 N/mm², while poplar revealed lower properties. The global comparative analysis indicated that birch and willow exhibited superior physico-mechanical properties compared with poplar. The mechanical properties were expressed by values located close to the lower limit of the recommended interval in the specialty literature [90]. The decrease in mechanical properties was attributed to the occurrence of knots in the wood. Knots are embedded basal portion of a branch and they render wood useless for certain applications, make the processing difficult and thus reduce the wood quality. However, according to the requirements of raw material presented in Table 9 the knots are allowed to produce strands for OSB production. Koman et al. [91] also found that the increase in the knot area resulted in a substantial decrease of MOE and MOR values.

4.4 Physical and Mechanical Properties- Evaluation of OSB Boards

The analyzed physical and mechanical properties of OSB boards are: density, modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB). The average values of the selected properties when compared with standard requirements are presented in Table 12. The overall results obtained for OSB properties met the EN standard of minimum requirements for OSB/2 boards, except the MOE of OSB made of poplar. The evaluation consists on comparative assessment of properties of OSB by implementation of interval plots with 95% CI for the mean values.

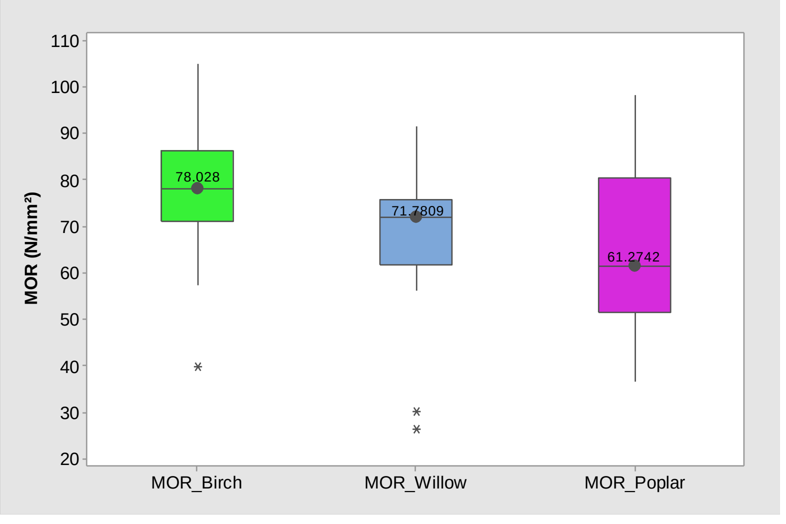


Fig. 11. Boxplot of MOR for the wood species under study [87]

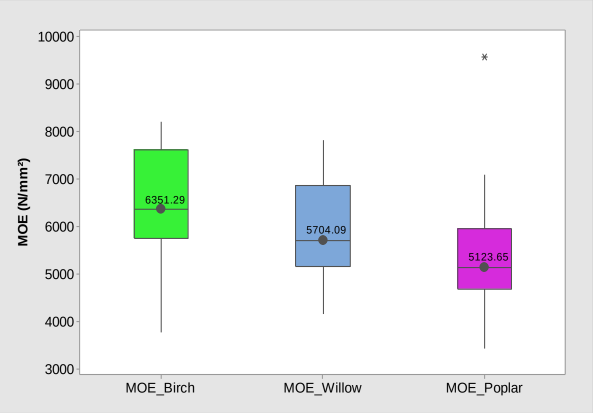


Fig. 12. Boxplot of MOE for the wood species under study [87]

Table 12. Average Values of Selected Properties of OSB Boards Made from Birch, Willow, and Poplar Strands [87]

Property of OSB/2	**EN 300 [6] Standard Requirement (For Board Thickness Range of 10 mm to 18 mm)**	**OSB/Birch 737.13 (kg/m^3)**	**OSB/Willow 689.71 (kg/m^3)**	**OSB/Poplar 727.19 (kg/m^3)**
MOR-major axis (N/mm^2)	20	36.0	36.6	43.3
MOR-minor axis (N/mm^2)	10	33	35.3	18.2
MOE-major axis (N/mm^2)	3500	5665	4636	3147
MOE-minor axis N/mm^2)	1400	4597	4543	2131
IB (N/mm^2)	0.32	1.05	1.33	1.28

Figs. 13 and 14 show that the OSB made of birch presented the highest median MOR values among the three species (MOR = 39.85 N/mm²; MOE = 5898.17 N/mm²). The MOR median values for all three species ranged in the same interval (MOR median max = 39.8579 N/mm², MOR median min = 35.3073 N/mm²). However, the MOR value of OSB made of poplar was higher than that obtained for OSB made of birch even though the two boards presented only small differences in density. Beck et al. [80] compared the impact of the species on the properties of OSB panels made from birch and poplar. The results showed that the bending strengths were higher for poplar boards compared to birch boards. Akrami et al. [81] found similar MOR values for OSB made 100% poplar (42.4 N/mm²) but a higher MOE value was observed when compared to the results of the present study. Out of the three types of boards the OSB produced from poplar strands presented the lowest mean value for MOE about 3147 N/mm². The comparative analysis of OSB boards indicated that the board made of birch presented superior elastic properties compared with the others. The IB values of the studied OSB/2 boards ranged from 1.05 N/mm² in case of OSB made of birch to 1.33 N/mm² for OSB board made of willow. Not much difference in terms of IB has been noticed for OSB made of poplar (1.28 N/mm²) when compared to OSB made of willow. Akrami et al. [81] found a lower value of IB for OSB boards made with 100% poplar (0.6 N/mm²) at a comparable OSB target density of about 710 kg/m^3. Paredes et al. [66] found IB results in the same range of 0.6 N/mm² in case of commercial OSB and made of red maple when using the same adhesive.

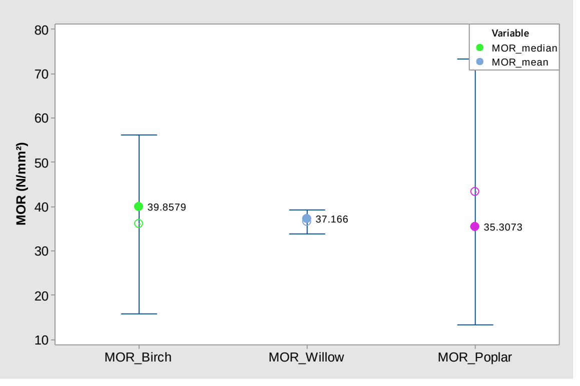


Fig. 13. Interval plot of MOR for OSB boards [87]

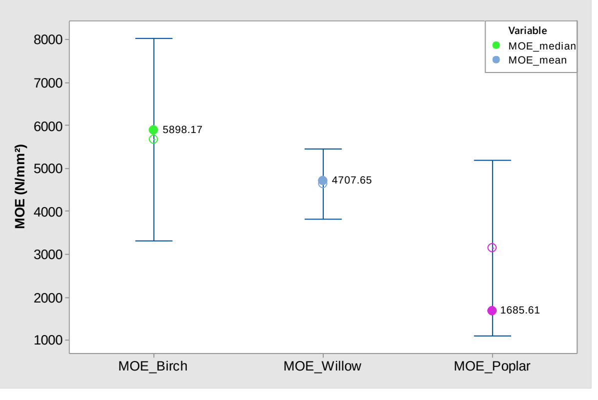


Fig. 14. Interval plot of MOE for OSB boards [87]

It appeared that all three wood species could be used as individual raw material in OSB production. Findings in the literature showed that the proportion of various species in the core and surface layers of OSB boards resulted in considerable differences of OSB properties. By increasing the amount of poplar strands in the core layer from 40% to 75%, a decrease of IB from 0.99 N/mm² to 0.27 N/mm² was noticed, while by increasing the proportion of beech strands an adverse trend was observed [81]. Therefore, future work on OSB properties manufactured from mixtures of species with various proportions in the core and surface layers are to be done in order to exploit the availability of such fast-growing species for a better capitalization of wood resource.

5. CONCLUSIONS

All properties of solid wood considered in this section had positive effects on the performance of OSB boards. For instance, considering the species of birch and willow, MOR for birch was higher than the one for willow, which makes it possible to increase MOR for birch OSB compared to willow OSB.

The overall results of OSB properties as 39 N/mm^2 for birch met the EN 310 (1999) requirements (major and minor axis) in the case of bending strength and EN 319 (1993) standard (in the case of internal bond) of minimum specifications for OSB/2 boards.

Poplar was found to be the most disadvantaged. However, the MOR of poplar OSB was higher than that one obtained from birch OSB even for small differences in density.

In terms of physical and mechanical properties, all three wood species could be used as individual raw material in OSB production. Therefore, results of this experimental work can find potential industrial applications in raw material species.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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