Evaluation of Selected Properties of Oriented Strand Boards Made from Fast Growing Wood Species

Adela-Eliza Dumitrascu,[a] Aurel Lunguleasa,[b] Emilia-Adela Salca,[b,]* and Valentina Doina Ciobanu [c]

Three fast-growing wood species in Romania, namely birch, willow, and poplar, were considered in this work. These species may have potential to replace softwoods or mixtures of wood species frequently used in the production of oriented strand boards (OSB). This study evaluated some physico-mechanical properties of these wood species that influence the performance of OSB boards made using 100% of strands from each individual species. Wood strands were cut, dried, screened, and sorted in order to form the core and surface layers of OSB boards. They were blended with a polymeric diphenyl methane diisocyanate adhesive (pMDI) and compressed with the help of a hydraulic press. The mechanical tests were performed under standard laboratory conditions. The obtained OSB boards made of each of the wood species met the EN standard of minimum requirements for OSB/2 properties, except the MOE of poplar-OSB, while its MOR was higher than that obtained for OSB made of birch even for small differences in board density. The birch-OSB presented superior elastic properties. Results of this experimental work can have industrial applications for an efficient use of low-grade raw material.

Keywords: Fast-growing species; OSB; pMDI; Physico-mechanical properties

Contact information: a: Department of Manufacturing Engineering, Transilvania University of Brasov, 5 Mihai Viteazul, 500174, Brasov, Romania; b: Faculty of Wood Engineering, Transilvania University of Brasov, 1 Universitatii, 500068, Brasov; c: Department of Silviculture and Forest Engineering, Transilvania University of Brasov, 1 Sirul Beethoven, 500123, Brasov, Romania;
**Corresponding author: emilia.salca@unitbv.ro*

INTRODUCTION

Oriented strand boards (OSB) are a substitute building material for plywood and particleboards (Irle and Barbu 2010). 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 (Barbuta *et al*. 2011, 2012; Jin *et al*. 2016; Salem *et al*. 2018).

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) (Egger 2017). Approximately 28% growth in the OSB market is expected by 2020 (Ferro *et al*. 2018). 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 (GWMI 2017).

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 (Mantanis *et al*. 2018). Compared with UF (62% solids) at 7% and 13%, pMDI (100% solids) at 4% and 6% results in superior board properties (Papadopoulos 2006). 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 (Brochmann *et al*. 2004; Malanit and Laemsak 2007; Paredes *et al.* 2008; Ciobanu *et al*. 2014; Salem *et al*. 2018).

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 (Okino *et al*. 2004; Febrianto *et al*. 2010; Hidayat *et al*. 2011; Sumardi and Suzuki 2014).

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 (Kretschmann *et al*. 1993). But Cloutier *et al*. (2007) demonstrated that strands made of juvenile wood of *Pinus radiata* can be used up to 70% in the manufacture of OSB for the surface layers, without a significant decrease of the OSB physico-mechanical properties. Moreover, there are various studies on juvenile wood of *Pinus* spp. and its use for OSB manufacturing (Rowell and Banks 1987; Wu *et al*. 2005; Han *et al*. 2006, Kohan *et al.* 2012). 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 (Cabral *et al*. 2006; Del Menezzi and Tomaselli 2006; Mendes *at al*. 2012).

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 (Beck *et al*. 2009; Akrami *et al*. 2014). Beech, a high density species widely spread in Europe and mostly used for particleboards production or as firewood, was subsequently considered for OSB manufacturing (Akrami *et al*. 2014).

Barnes (2000) 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*. (2010). The most important influencing parameters of OSB boards are: wood species elastic properties, their rate in the structure, strands orientation, and density profile (Arnould *et al*. 2010). The OSB performance depends on the mechanical properties of individual wood strands which can be connected to the macroscopic mechanical behavior of wood itself (Han *et al*. 2006; Arnould *et al*. 2010). Such an approach is presented by Dixon *et al.* (2017) 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 (Via *et al.* 2011).

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.

EXPERIMENTAL

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 (Table 1).

Table 1. Conditions for the Raw Material Imposed by the OSB Manufacturer

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 material in the form of solid wood and strands was prepared at the company. Table 2 presents the selected physico-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 2. Selected Properties of Wood Species and OSB Boards

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 (2014)			-
	Gravimetric method	Universal machine IB 600 (IMAL, Globus Group, San Damaso, Italy)		-
	20	10	10	-
OSB	EN 323 (1993)	EN 310 (1999) (major and minor axis)		EN 319 (1993)
	Gravimetric method	Universal machine IB 600		
	25	5+5	5+5	5

The wood samples were cut at standardized dimensions for each one of the properties listed in Table 2. 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.

Wood strands from each wood species were produced at dimensions in the range of 15 mm to 25 mm wide, 75 mm to 120 mm long, and 0.3 mm to 0.7 mm thick under industrial conditions with a high-capacity splitting machine having 52 knives. The dimensions of the strands were different because the wood is not homogeneous. 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. Moreover, the flakes are sorted, resulting in large flakes for the face and smaller flakes for the core. They were dried in a laboratory oven at 90 °C for 4 h until they reached 10% MC. The wood strands were then screened and sorted to form the core and surface layers, respectively. They were blended with a pMDI adhesive (10%) of LUPRANATE M20S type (BASF Company Ltd., Jung-gu Seoul, Korea). The adhesive had a viscosity at 25 °C of about 170 mPa to 250 mPa and a density of 1.23 g/cm^3. No wax or other additives were used.

The mat was manually formed having 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.

Three boards of OSB/2 type (load-bearing boards for use in dry conditions) with dimensions of 440 x 440 x 12 mm and density of 610 kg/m^3, one board made from each one of the species under study were manufactured by using a laboratory single-plate hydraulic press. The mat was compressed at the temperature of 180 °C and a specific pressure of 3 MPa. After pressing all boards were cooled at the room temperature for 48 h and prior to testing they were conditioned at 65% RH at room temperature. The OSB samples used for the tests had about 10% MC.

Statistical Analysis

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.

RESULTS AND DISCUSSION

Analysis of Physical Properties for Wood 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. 1). 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 (Wagenführ 1996).

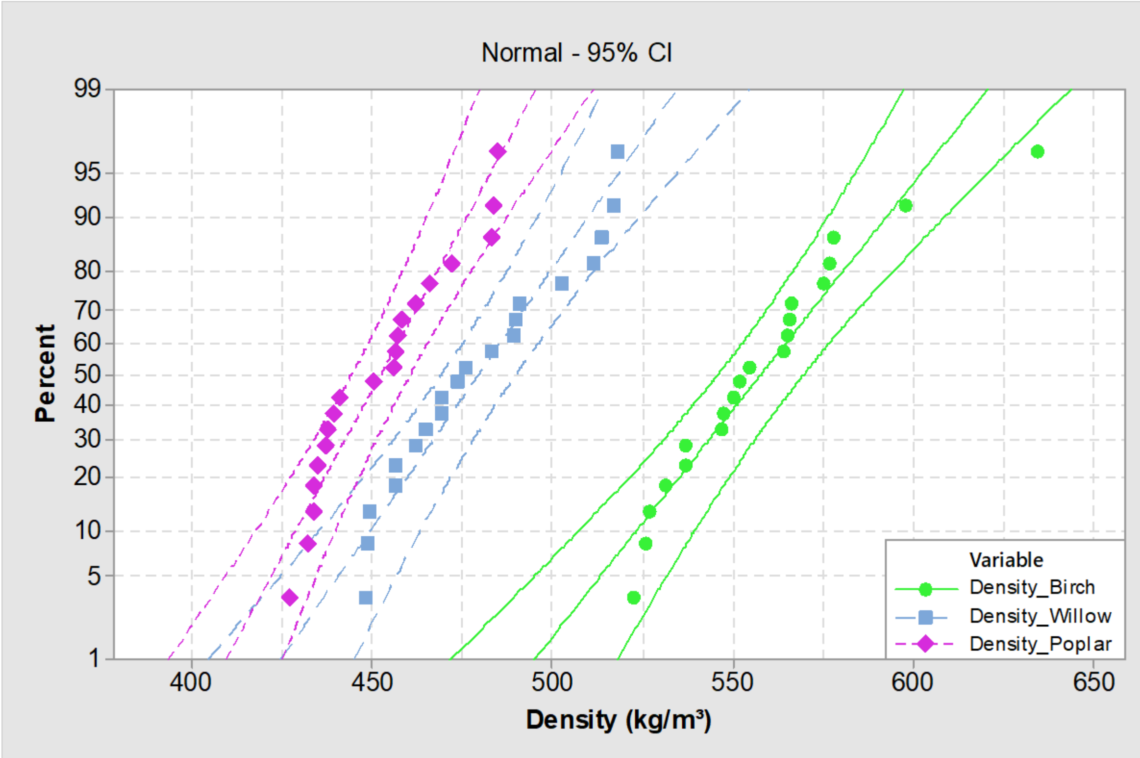

Fig. 1. Probability plot of density for analyzed wood species

Analysis of Mechanical Properties of Wood Raw Material

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. 2 and 3. As expected, MOR and MOE values decreased gradually with the species density.

Extreme low values for MOR were recorded for birch and willow (Fig. 2). 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 (Wagenführ 1996). 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 1 the knots are allowed to produce strands for OSB production. Koman *et al*. (2013) also found that the increase in the knot area resulted in a substantial decrease of MOE and MOR values.

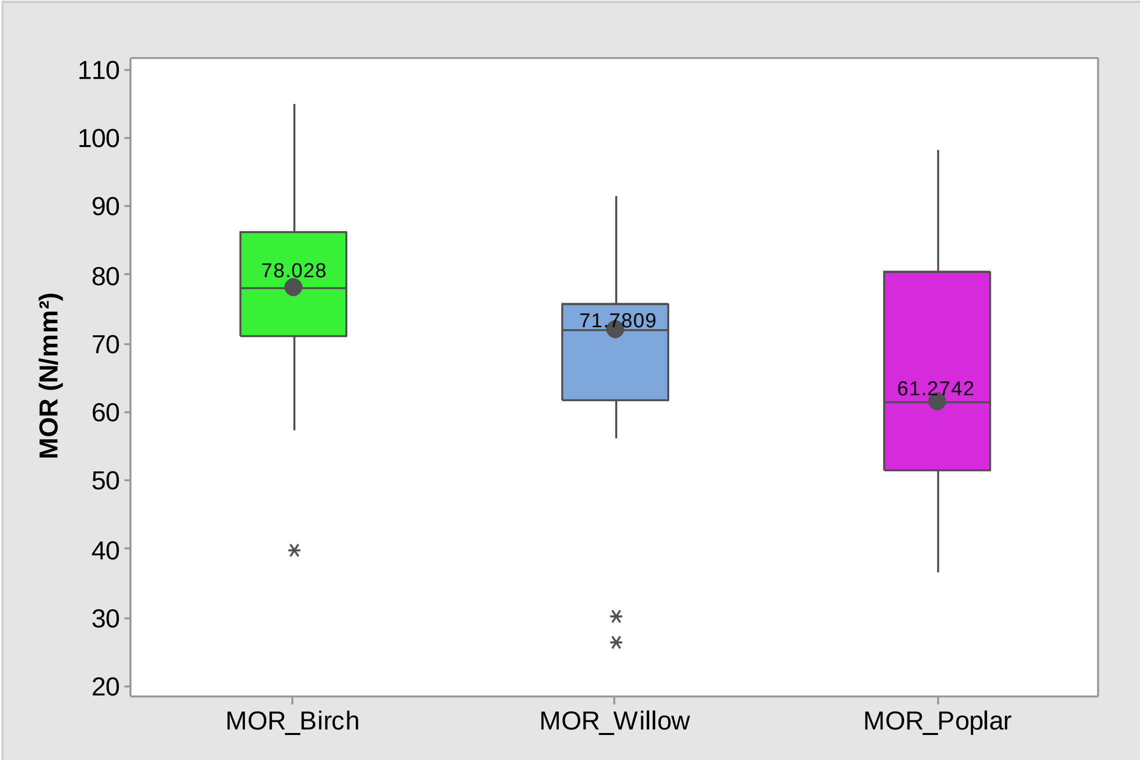

Fig. 2. Boxplot of MOR for the wood species under study

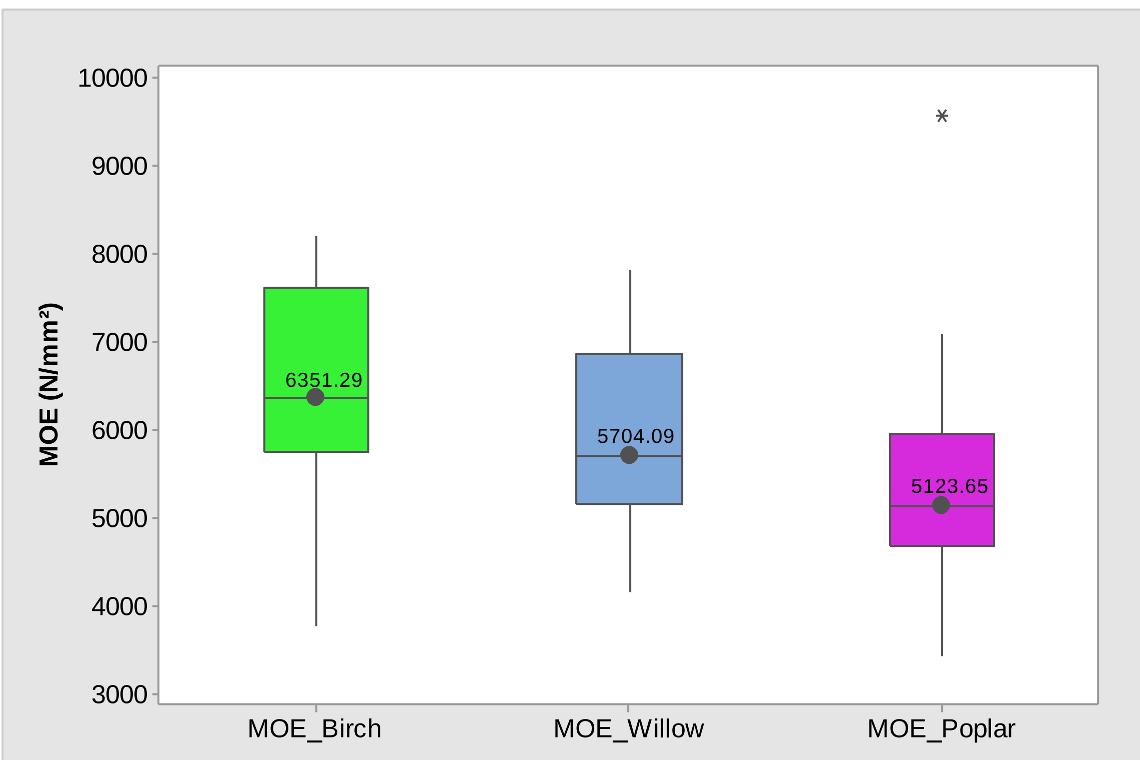

Fig. 3. Boxplot of MOE for the wood species under study

Analysis of Physical and Mechanical Properties of OSB

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 3. 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.

Table 3. Average Values of Selected Properties of OSB Boards Made from Birch, Willow, and Poplar Strands

Property of OSB/2	EN 300 (2006) 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-major axis N/mm^2)	1400	4597	4543	2131
IB (N/mm^2)	0.32	1.05	1.33	1.28

Figures 4 and 5 show that the OSB made of birch presented the highest median MOR values among the three species (MOR = 39.85 N/mm^2; MOE = 5898.17 N/mm^2). The MOR median values for all three species ranged in the same interval (MOR median max = 39.8579 N/mm^2, MOR median min = 35.3073 N/mm^2). 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*. (2009) 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*. (2014) found similar MOR values for OSB made 100% poplar (42.4 N/mm^2) 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/mm^2. 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/mm^2 in case of OSB made of birch to 1.33 N/mm^2 for OSB board made of willow. Not much difference in terms of IB has been noticed for OSB made of poplar (1.28 N/mm^2) when compared to OSB made of willow. Akrami *et al*. (2014) found a lower value of IB for OSB boards made with 100% poplar (0.6 N/mm^2) at a comparable OSB target density of about 710 kg/m^3. Paredes *et al*. (2008) found IB results in the same range of 0.6 N/mm^2 in case of commercial OSB and made of red maple when using the same adhesive.

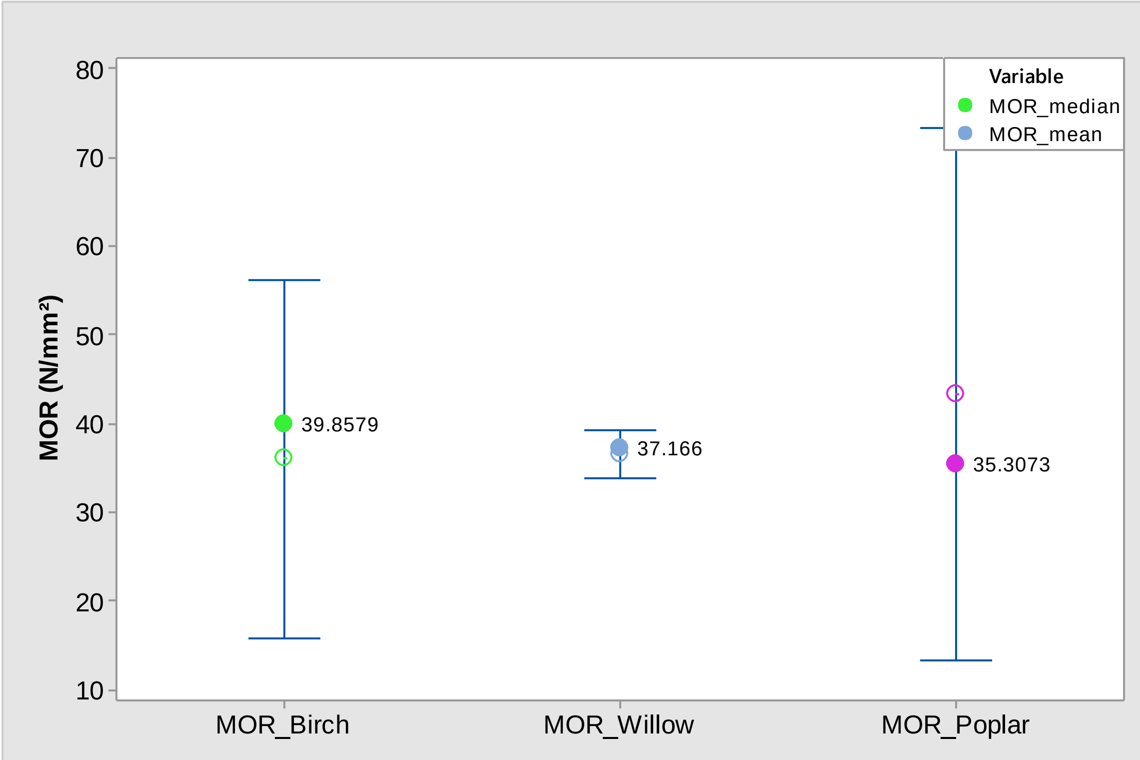

Fig. 4. Interval plot of MOR for OSB boards

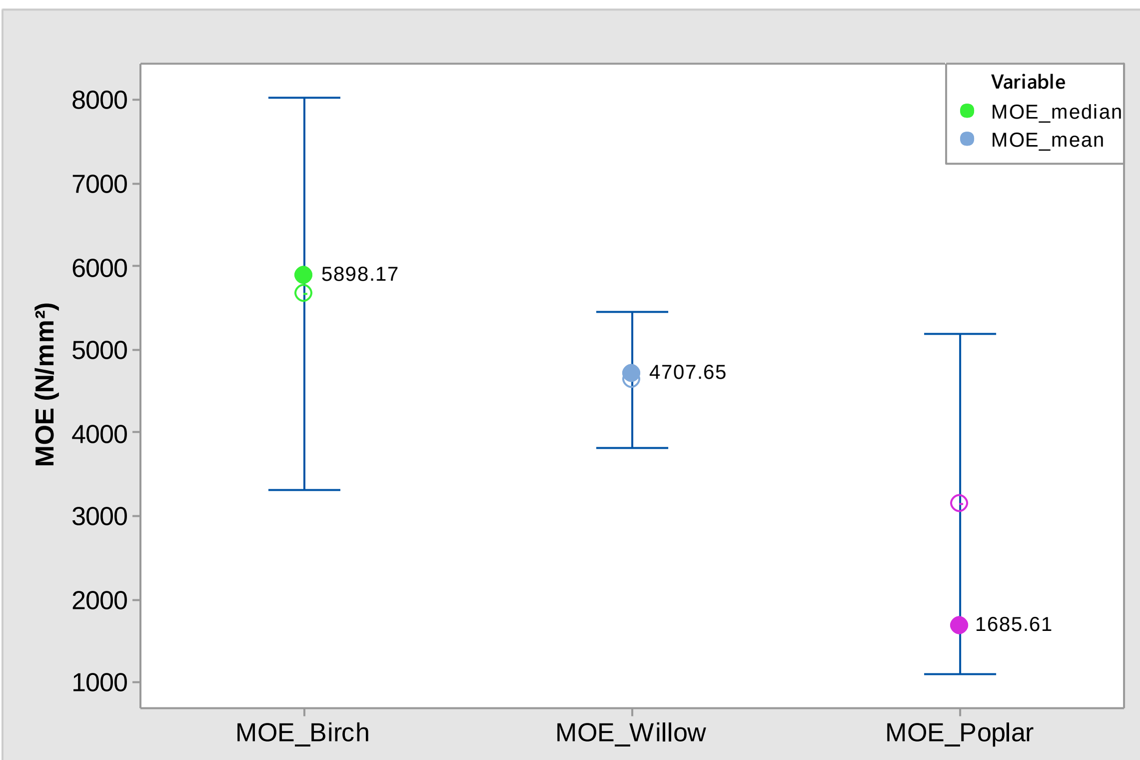

Fig. 5. Interval plot of MOE for OSB boards

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. Akrami *et al*. (2014) found that 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.

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.

CONCLUSIONS

1. All properties of solid wood considered in this work had positive effects on the performance of OSB boards. For instance, considering the species of birch and willow, MOR for species birch (78 N/mm^2) was higher than willow (71 N/mm^2), which makes it possible to increase MOR for birch OSB (39 N/mm^2) compared to willow OSB (37 N /mm^2).
2. 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.
3. From the three analyzed wood species, poplar was found to be the most disadvantaged. However, the MOR of OSB made from poplar (43 N/mm^2) was higher than that obtained from OSB birch (36 N/mm^2) even for small differences in density.
4. 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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